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SOME FACTORS INFLUENCING GAS SORPTION AND DESORPTION
FROM CERTAIN WESTERN CANADIAN COALS

by



Magdy W. Mikhail

A Thesis

Submitted to the Faculty of Graduate Studies
in Partial Fulfilment of the Requirements for the Degree
of Master of Science in Mining Engineering

DEPARTMENT OF MINING AND METALLURGY

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The undersigned certify that they have read, and
recommend to the Faculty of Graduate Studies for acceptance,
a thesis entitled

SOME FACTORS INFLUENCING GAS SORPTION AND DESORPTION

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ABSTRACT

Studies were made of the index of speed of desorption (ΔP) and of total and apparent sorption capacities of coals from three Western Canadian seams. ΔP measurements were made using the standard particle size range (-32 +60 mesh) and the coals were classified to indicate the degree of danger to sudden outbursts of methane. Approximate relationships were found between the ΔP_{0-10} and ΔP_{0-60} indices and between coal rank and the ΔP_{0-60} indices. The degree of fissuration was estimated from ΔP measurements on particles of different sizes. Apparent and total sorption capacities were determined by using volumetric and gravimetric methods, and sorption isotherms were prepared for carbon dioxide and methane for pressures up to 600 psig. The effect of moisture content (0 - 3.4%) and temperature (4.4 - 54°C) on the sorption of methane was examined. The gravimetric method was found to have several distinct advantages over the previously-used volumetric method.

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CHAPTER I

INTRODUCTION

In recent years, coal production has begun to increase rapidly in Western Canadian coal fields and the output of metallurgical coal is expected to reach about 20-25 million tons per year by 1975 (Berkowitz)*. By the end of this century, it is expected that production must be entirely from underground because of depletion of the near-surface deposits. This means that production will gradually increase from underground mines in the near future.

Increase in production from underground faces (in many cases) will lead to an equivalent increase in gas emission. The effect of mining is to disturb the equilibrium of rock pressures and of gas pressures. This results in a greatly increased gas emission due to the pressure gradients created and the increase of effective permeability due to relaxation of the strata surrounding a mine opening. The size of the openings greatly effects the extent of relaxation, and more emission is to be expected from long working faces than from short faces. Further gas emission will result from the broken material as it is excavated, the amount of gas depending on the degree of comminution as well as on the amount originally contained by the coal.

The anticipated increase in emission due to the increase of production from highly mechanized faces indicates

*References are listed alphabetically on pages 120-121.

the need to study the mechanisms of gas release and the factors that control it. The study of gas emission may help production engineers estimate and control gas release from working faces and so reduce the hazards of fire and explosion and of sudden outbursts. Detailed studies of the gas emission from representative samples from a certain seam may help the engineer in choosing the dimensions of new working faces in order to reduce or minimize concentrations of gas. Reasonable estimations for the expected amount of gas to be released should also help in the design of efficient ventilation layouts for new faces or mine districts.

The investigations described in this thesis were intended to provide more knowledge of the sorption capacity and the index of speed of desorption (ΔP)* of some Western Canadian Coals. The relationships between the sorption capacity of coal and gas pressure for methane and carbon dioxide were investigated for pressures up to 600 psig, and the effect of temperature and moisture content on the sorption of methane were examined for various temperatures and moisture contents. Results obtained by using a gravimetric method for measuring the amount of gas sorbed by coal were compared to the results obtained by a volumetric method which has previously been used and described.

Other work involved the determination and study of ΔP indices for certain coal samples. The relationship between ΔP values and particle sizes was investigated as a

*Procedure for determining this index described on pages 34-35.

means of determining the degree of fissuration by applying a method developed earlier by workers at CERCHAR (Study and Research Centre of the Collieries Board of France).

CHAPTER II

REVIEW OF PREVIOUS INVESTIGATIONS

1. Introduction

The importance of carrying out studies on factors that influence firedamp* emission had been realized several decades ago. The practical purposes of studying these factors were to enable estimation and perhaps control of the amount of gas released during mining operations, to develop methods of draining gas from coal seams prior to mining, and to predict and if possible prevent sudden outbursts of gas. Extensive studies have been done in many countries, especially those where seams occur having excessive amounts of firedamp or carbon dioxide or where accidents have occurred due to instantaneous outbursts, particularly in the Soviet Union, France, Germany, Belgium, Poland and Great Britain. These studies have included field and laboratory work to study three factors which are considered to be of basic significance, namely pressure, structure of the coal, and the amount of gas contained by the coal.

In the following sections a review is given of certain previous studies concerning the fine structure of coal and the sorption of gas, including the influence of gas pressure and moisture content on sorption capacity.

*Firedamp - gas from coal, principally methane.

2. Coal Structure

2.1 General

The structure of coal (as a material and as distinguished from the structure of a coal seam or a coal basin) includes pores and fissures of different sizes which influences many of its chemical, physical and mechanical properties such as gas sorption, moisture capacity and coking properties. The pores are of natural origin and are assumed to be more or less spherical and unaffected in size by stresses and they are generally considered to govern the adsorption capacity. On the other hand, the fissures which close under stress are generally considered to govern gas permeability. These can be natural or caused by the influence of mine work. An increase in fissuring when the coal mass relaxes facilitates and speeds up the release of firedamp.

Measurements of fissuration have been carried out extensively by Russian, French and Belgium investigators. Direct fissuration measurements are helpful in characterizing the structure of the coal in a seam but unfortunately the methods of making such measurements are tedious and complicated. Recently, procedures to determine the index of speed of desorption (ΔP) and the mechanical fragility have been used as indirect methods to measure fissuration. Further details about direct and indirect methods of measuring fissuration are discussed later.

2.2 Size of Pores and Fissures

Khodot (1964) has reported a convenient size classification of pores and fissures and noted their significance with regard to the retention and release of gas, namely,-

- a) Ultrapores or micropores with diameters up to 100 \AA , studied by X-ray structural analysis and sorption analysis methods. These provide most of the surface area on which sorption can take place.
- b) Intermediate pores with a diameter of 100 to 1000 \AA (from 10^{-6} to 10^{-5} cm), studied by the electron microscope. He considers these to control the gas diffusion properties of coal.
- c) Sub-macropores with a diameter of 10^{-5} to 10^{-4} cm (from 0.1 to 1.0 \mu), studied by the electron microscope. These control slow laminar filtration.
- d) Macropores with a diameter of 10^{-4} to 10^{-2} cm (1 to 100 \mu) studied by optical methods. These influence laminar filtration.
- e) Visible pores and fissures of 10^{-2} cm and more, which are distinguishable by the naked eye. These influence or control both laminar and turbulent filtration.

Khodot assumes pores to have dimensions of the same order in all directions; the volume of pores constitutes up to 10% of the volume of the coal and is considered to be relatively stable, varying little, if at all, with coal pressure. Experimental studies by Khodot et al (1967) in

coal specimens relieved from 'in-situ' pressure also gave a value of up to about 10% for the volume of the fissures. They consider that the volume of fissures in coal is unstable and depends markedly on the confining pressure.

2.3 Origin of Natural Fractures and Fissures

Taylor reported that natural fractures and fissures may be classified in three main groups according to origin:

- a) Endogenetic
- b) Exogenetic
- c) Hypergenetic

a) Endogenetic fractures

Endogenetic fractures are formed during the process of coalification. They are thought to have been caused by non-uniform decrease in the volume of coal and associated strata due to shrinkage during maturation and to changes in stress conditions. This has resulted in tensile strains and subsequent fracture. The frequency and extent of fracturing are closely connected to the degree of maturation of the coal and also to its petrographic composition. Greater numbers of fractures have been observed in high rank than in low rank coals and they are more prevalent in the bright than in the dull constituents. They are generally oriented at right angles to the bedding planes although some have been observed parallel to the planes of stratification.

b) Exogenetic fractures

Exogenetic fractures are formed by tectonic actions of compression or tension or shear to which a coal seam may have been subjected, their frequency of occurrence depending on the amount of tectonic action experienced. This type of fracture, unlike the endogenetic fracture, usually occurs parallel to, or at some angle (up to about 80°) to the bedding planes. Exogenetic fractures are evident in seams containing a high proportion of bright coal i.e. vitrain.

c) Hypergenetic fractures

Hypergenetic fractures occur in these seams which are close enough to the surface to have undergone oxidation or weathering by percolating ground water set. They form at right angles to existing fractures, and their extent is very small and localized within individual layers of a seam.

Endogenetic fractures, having been formed by shrinkage and tensional forces, will be open and hence highly conductive for gas migration into the adjacent strata. They will, however, often be blocked by mineral inclusions which have been deposited in them.

Exogenetic fractures produced by compressive forces will have low effective permeability, the fractures often being filled with tightly packed, finely ground coal. On the other hand, those formed by tensional forces provide paths

of high permeability, which are conductive for gas migration throughout the seam, resulting in an even distribution of pressure and volume.

2.4 Measurement of Fissuration

A visual method of measuring the degree of fissuration of coal samples was originally developed by Russian scientists (Alpern). Microscopic examination of polished sections in reflected light was used to count the number of fissures in samples of different coals. The examination was made on polished surfaces, cut perpendicular to the stratification, which had been previously cast and impregnated with plastic material under vacuum. Fissures were counted on two orthogonal profiles of 5 cm each. The degree of fissuration was established by determining the average distance between fissures. Five classes of fissuration were defined by Alpern according to a rising number of fissures per centimeter. as follows:

<u>Class</u>	<u>Mean distance between fissures/mm</u>	<u>Mean number of fissures/cm</u>
I	1.6	6.25
II	0.5	20.0
III	0.14	71.4
IV	0.05	200.0
V	0.008	1225

However counting of fissures is slow and expensive owing to the practical difficulty of counting the large number of fissures, and it requires a rather lengthy preparation of samples. This is why interest is now disposed

toward indirect methods of studying the fine structure of coal, such as determining the fragility index of coal and the index of speed of desorption ΔP .

Alpern investigated the fissuration of coal by determining the mechanical fragility (fragility index). This index is determined by placing a given weight of coal in a rotary drum. After a certain number of rotations the sample of coal is removed, sieved, and weighed for the following three size fractions:

1	> 4 mm	(% weight is P_1)
2	0.5 - 4 mm	(% weight is P_2)
3	< 0.5 mm	(% weight is P_3)

The fragility index 'F' is then calculated,-

$$F = P_1 + 10P_2 + 100P_3 \times \frac{1}{100}$$

Alpern found a fairly good correlation between the fragility index and the direct measurement of fissuration.

The ΔP index characterizes the initial rate of desorption which apparently depends on fissuration. It is measured on coal samples from which the gas has first been evacuated and which have subsequently been saturated with gas in pre-determined conditions. Details of test procedures to obtain this index are given in Chapter III.

Belin and Chiche (1962) have shown a relation between the ΔP index and fissuration experimentally. To do this they classified coal samples in five different groups according to the increasing number of fissures per centimeter, employing

a scheme similar to the Russian classification of the frequency of fissures mentioned previously, namely,-

<u>Class of fissuration</u>	<u>Mean distance between fissures (and size range)</u>
I	> 1.6 mm
II	1.6 - 0.5 mm
III	0.5 - 0.16 mm
IV	0.16 - 0.05 mm
V	0.05 - 0 mm

Then they compared the classes of fissuration as determined by counting fissures under the microscope with classes deduced from ΔP measurements on different size ranges. The ΔP class of fissuration corresponded to the smallest size range in the above tabulation at which the ΔP index abruptly began to increase over that of the next larger size range.

Table 2-1 shows an example presented by these investigators of a comparison (for nine different samples of coal) between the classes of fissuration as determined directly by counting and those established from ΔP index measurements.

TABLE 2-1

<u>Fissuration class by microscope</u>	<u>Fissuration class by ΔP</u>
II	III
IV	III
III	III
III	III
III	II or III
III	III
III	III
II	III
II	II

This table shows that the classifications as measured by the microscope and as inferred from ΔP values are not always identical but are similar enough that for practical purposes ΔP procedures may be used as a means to establish classifications of fissuration.

The experimental work of Belin and Chiche in measuring the ΔP index of the above five ranges of size showed that ΔP indices of various sizes of fragments stay practically constant as long as the size of the coal particles is less than the distance between fissures, then the ΔP index increases as particle size is reduced, because grinding develops more new exterior surfaces than were originally available because of fissures. In other words, the size of particles at which the ΔP index begins to increase abruptly corresponds closely to the spacings of the fissures.

3. Stress Conditions

Since fissures can be caused by the influence of mine operations, it is appropriate to review the effects of mining on the enclosing rocks and on the coal in the neighborhood of the working places. Before mining commences the stresses in a coal seam are in a state of equilibrium. Immediately after an opening is made, restraint is removed from one direction and redistribution of the stresses occurs. The vertical stress no longer acts above the excavation but is partially transferred to each side of it resulting in increased loading in these regions accompanied by a reduction

in pressure above the excavation. The region in which the stresses are reduced near the working face is known as the relaxed zone and its size will vary according to the magnitude of the excavation. The areas where the pressure has been increased above the normal pressure are known as abutment zones. The increased load in these zones may be greater than the load-carrying capacity of the rock or coal, thus resulting in failure. This failure causes the abutment zone to move further into the solid, and consequently the size of the relaxed zone increases. Thus re-distribution of stresses often leads to fracturing, the degree of fracturing depending on the load and strength of the coal within the relaxed zone; this gives rise to a large volume of coal of increased permeability from which gas can be readily emitted.

4. The Amount of Gas in Coal

4.1 Nature and Origin of Gas in Coal

The principal constituents of gas in coal seams are methane and carbon dioxide, with sometimes a few percent of nitrogen. Very small amounts of rare gases such as argon are occasionally found. In most seams methane is the major gas constituent. The origin of methane in coal can be briefly shown in the three stages of transformation of organic materials as summarized by Schneider.

- a) When the original vegetation material is at or near surface micro-organisms cause decomposition of the organic materials, and CO_2 , NH_3 , N_2 and CH_4 are emitted as by-

products of decomposition and escape to the atmosphere.

- b) Decomposition under water in the biochemical zone can lead to the formation of lignites or sub-bituminous coal. The coal retains little free gas due to the shallow depth. Carbon dioxide and nitrogen are present in the sorbed state. These types of transformations can continue, with certain variations, at shallow depth and under a bed of alluvial or argillaceous material.
- c) As the seams are more deeply buried, metamorphism, as a result of higher temperature and pressure, causes increases in rank with production of methane as the principal gas. Tectonic influences can cause further metamorphism of the coal.

Generally it is considered that methane is formed deeply below the surface, while carbon dioxide and nitrogen are formed close to the surface. Carbon dioxide is essentially a product of biochemical transformations, but it can be formed also by oxidation of coal and also introduced by igneous intrusions. Nitrogen, according to Schneider, is of atmospheric origin like the rare gases. As a generalization, it would appear that in very low rank coals the predominant gas is carbon dioxide, in coal of the sub-bituminous to semi-anthracites range it is 90-95% methane, whilst in the very high rank anthracites the seam gas contains even higher amounts of methane (Taylor). Nevertheless carbon dioxide has been found to predominate in certain French, Polish and Australian seams of mature coal.

4.2 Sorption of Gas by Coal

The process of taking up a gas or vapour by a solid is known as sorption, the opposite process being known as desorption. The term sorption includes both adsorption and absorption. Adsorption is the term used to describe the existence of a higher concentration of a particular substance at the surface of a solid than is present in the bulk of the solid, where as absorption describes a more or less uniform penetration into the molecular structure of a solid by a given substance.

Coal is readily able to sorb gases, including carbon dioxide, methane and nitrogen. The sorption of gas by coal and the factors that influence its sorption capacity have been studied by several workers. It was believed until the beginning of the twentieth century that the gas contained by coal was simply compressed as free gas in cavities, but subsequently it was realized that the amount of sorbed gas far exceeds the retention capacity of the cavities alone.

Graham (1921-1922) studied the sorption of gases in coal as a part of an investigation into the release of large quantities of methane from coal in English coal mines. He showed that the amount of methane or carbon dioxide sorbed by coal is much greater than the amount of gas that could be compressed in the cavities. To explain this apparent anomaly it was suggested that sorption of firedamp can take place in three main categories; (a) Compression of gas in coal pores, (b) Adsorption on the internal surfaces, and (c) Solid solu-

tion of gas in the coal matter. According to Taylor, only the gas that is compressed in pores and adsorbed by coal surfaces is of practical importance in mining operations.

Some years later, Moffat and Weale measured the total sorption capacity and the apparent sorption capacity of methane at pressures up to 1000 atmospheres for some English coals. They distinguished between two values of sorption capacity as follows:

- a) The total sorption capacity is the quantity of gas sorbed by the entire lump volume of the coal and includes gas which is simply compressed in the pore spaces as well as adsorbed gas.
- b) The apparent sorption capacity is the volume of gas adsorbed on the coal surfaces only, and does not include the compressed gas in the pore spaces and fissures.

The porosity 'f' in percentage is the volume of voids to the total volume, and may be calculated as

$$f = 100 \left(1 - \frac{\delta}{d} \right)$$

where δ is the apparent specific gravity

d the true specific gravity

The volume of free gas retained in the pore spaces under pressure is in accordance with the modified form of Boyle's law, and its value at any pressure can be found from the equation

$$V = \frac{P}{P_1} \frac{f}{c}$$

where V = volume of gas in pore space cm^3/gm ,
expressed at atmospheric pressure.

P = gas pressure in atm.

f = porosity in %

q = apparent specific gravity of coal, cm^3/gm

c = compressibility factor of gas

The amount of sorbed gas in coal is affected by many variables such as the nature of the gas, the nature of the coal, the presence of moisture, and the pressure of the gas. Its quantity is proportional to the area of the surface of contact of the coal, and depends on the physico-chemical nature of gas. This volume increases with a decrease in temperature and moisture content, and vice versa. The relation between the quantity of gas and its pressure for a given temperature can be shown graphically as a sorption isotherm.

Palvelev studied the sorption of methane by coal from the Donbass at high pressures. His sorption isotherms showed a saturation limit at pressures of the order 100 - 150 kg/cm^2 (1422 - 2133 lb/in^2) after which the amount of sorbed methane remained constant (He explained that Coppen's conclusions that experimental curves pass through a peak is due to a probable error in determining the real specific gravity of coal and definitely not due to expansion in coal volume by sorption at high pressures). He indicated that at pressures below 100 $\text{kg}/\text{sq.cm}$. most of the methane present in coal is that which is in the sorbed state while above pressures of

100 - 200 kg/sq.cm. the quantity of methane contained in the pores of the coal exceeds that of sorbed methane. Taylor stated that Palvelev's conclusions are consistent with English work and that above 100-150 atmospheres the increase in the total sorption of methane by coal is mainly due to the compression of free methane in the pores.

Jolly and his associates investigated methane sorption and its relationship to gas pressure up to 1400 atm. for some British coals. They showed two curves for each coal, firstly a total gas isotherm, showing the gas which is both sorbed on the surfaces of coal and compressed within the pore spaces, and secondly an isotherm of sorbed gas showing only that which is sorbed on the coal surfaces. However their results appear to show different values of pressure at which the amount of methane compressed in pores exceeds that of sorbed methane than those of Palvelev. For example they found that the amount of sorbed gas is over 10 times the compressed gas at 600 psig.

Schneider reported that under the actual conditions of Soviet seams, it was estimated that the free gas in coal represents only 15-25% of the total amount of sorbed gas.

Two general methods have been used to measure the capacity of coal to retain gas, volumetric methods and gravimetric methods. For example Graham (1921-1922) and Palvelev used volumetric methods to measure desorption of gas from coal, while Jolly used a volumetric method to measure the sorption of gas into coal. On the other hand,

Khodot, et al (1967) and Gunther have used gravimetric methods to determine methane sorption. The most recent and complete description of a gravimetric method was reported by Daines. (This method is described in more detail in Chapter III).

According to Millard, on the basis of studies of adsorption Langmuir assumed that an adsorbing surface can be covered by a mono-molecular layer, which is held by the field of force of the surface atoms. He supposed that molecules striking an already-covered site are promptly repelled or evaporated i.e. that an equilibrium is reached when the rate of condensation of gas molecules is equal to their rate of evaporation. On these assumptions Langmuir derived the following equation:

$$V = \frac{K_1 P}{K_2 P + 1}$$

where V = volume of adsorbate

P = pressure of gas

K_1 and K_2 are constants

Jolly re-arranged Langmuir's equation in order to test it against experimental data i.e.:

$$\frac{P}{V} = \frac{K_2 P}{K_1} + \frac{1}{K_1}$$

If P/V is plotted against P , a straight line should thus be obtained which has a slope K_2/K_1 and intercept $1/K_1$.

Palvelev, Jolly, Taylor and others have tested Langmuir's equation against experimental data and found it

to be generally applicable to methane sorption by coals in the range of pressures up to 1000 kg/cm^2 ($14,200 \text{ lbs/in}^2$). Both Palvelev and Jolly pointed out, however, that although their experimental results agree with Langmuir's equation, they do not necessarily prove the existence of a perfect mono-molecular layer of methane molecules. Jolly et al stated that "conformity would best be described as the result of the simultaneous occurrence of compensating effects and that the picture conveyed by the Langmuir equation is a very simple one".

4.3 Moisture Content

Moisture, as is well known, affects the sorption of gases. Graham (1921), in his studies of the sorption of dried and moist coals for methane, carbon dioxide, and other gases, observed that the effect of moisture on the sorption capacity is very evident even at high pressures.

According to Gunther an empirical formula was developed by Ettinger to estimate the total sorption of gas for moist coal from the total sorption capacity of dry coal:

$$\frac{\text{Total sorption capacity of humid coal}}{\text{Total sorption capacity of dry coal}} = \frac{1}{1 + 0.31H}$$

where H is the moisture content in percentage. Gunther considers, on the basis of his own studies, that Ettinger's formula represents sufficiently well the actual effect of moisture content on total sorption capacity, although he noted that comparison of test results to those calculated from the formula show some dispersion.

5. Gas Pressure

The pressure of gas has an important influence on its emission from a coal seam, not only because it is related to the amount of gas capable of being desorbed but because it also influences the rate of emission. The introduction of a free face in otherwise undisturbed strata results in the establishment of a gradient in gas pressure between the seam and the opening, similar in magnitude to that between the gas pressure in the seam and the surface. The flow of gas is increased where the pressure gradient is higher.

Measuring the pressure of gas in the coal seam ahead of working faces should be useful in predicting the amount that can be released. Unfortunately it is very difficult and sometimes impossible to measure gas pressure in a coal seam due to the escape of gas during drilling. For example, Vandeloise (1964) and Gunther have indicated that gas pressure measurements in situ are not absolutely reliable. Khodot (1964) reports that gas pressure in coal seams, as measured from boreholes, does not normally exceed 30-40 atmospheres, although in rare cases it may rise to 70 atmospheres.

CHAPTER III

EXPERIMENTAL STUDIES

1. Introduction

Although some factors affecting firedamp emission from coal must be investigated underground, others are best studied in the laboratory. Some of these factors are inter-related so it is extremely difficult, if not impossible, to study them individually in a mine due to the impossibility of controlling their magnitudes and variations.

The main purposes of the experimental investigations herein described were:

- a) To indirectly study the structure of certain coal samples.
- b) To study the sorption capacity of coal and the factors which control it, such as pressure, temperature, moisture content, rank and porosity.

Three different types of tests were carried out on coal from three different sources. Studies were made of the following:

- a) Index of the speed of desorption (ΔP) for methane, in order to:
 - i) Classify certain samples of coal according to this index.
 - ii) Study the relationship between the ΔP index and the size of coal fragments, and to classify the degree of fissuration of coal samples by means of this relationship.

- b) The apparent sorption capacity for methane and carbon dioxide of different composite samples of coal, as measured by a volumetric method at 50 psig.
- c) The total sorption capacity of coal for methane and carbon dioxide, as measured by a gravimetric method at pressures up to 600 psig, in order to:
 - i) Test the reliability and accuracy of the method.
 - ii) Compare measurements of sorption capacity by volumetric and gravimetric methods on samples at 50 psig.
 - iii) Establish or determine the sorption isotherms for coals from different mines, seams and locations.
 - iv) Study the effect of changes in temperature (over the range 4.4°C to 54°C) on sorption capacity at different values of gas pressure (0-600 psig).
 - v) Study the effect of changes in moisture content (over the range of 0 to 3.5% moisture) on sorption capacity at different values of gas pressure (0-600 psig).

2. Source of Coal Samples

The coal samples used for these tests were taken from mines belonging to three different mining companies, and from each mine samples were taken from several locations. Channel samples were cut across seams from the roof to the floor of the working places. The channels were about 4 inches in width, 2 inches deep, and about 1.0 - 3.0 feet in length. Visible variations in the appearance of the coal bands were the main control of the sample lengths. The coal faces were first cleaned and examined carefully for variations in coal

quality along the sample sections to decide the length of each sample. Sampling locations were chosen as close to working faces as possible in order to minimize the possibility of taking oxidized samples.

A visit was made on June 3, 1969 to mines of Kaiser Resources Limited at Natal, B.C., and samples were taken in the Balmer North Mine from the Balmer west seam. The coal seams in the Crowsnest area were laid down in the Lower Cretaceous period. There has been a variable amount of faulting and folding which has caused the coal to be sometimes intensely sheared and very friable (Norris) while in other areas it is fairly solid as in some of the samples taken on the visit. The coal of the Balmer west seam is mainly low volatile bituminous in rank with the top band sometimes falling in the medium volatile bituminous classification. Samples were taken from three different locations in the seam, which were approximately 600 feet below the surface. Three samples were taken from the Face of 5 Entry, 202 Panel. These samples (Nos. 937-939) were mainly of very soft dull coal with bright bands. Samples 943-947, from the 3 Main 202 Panel, 2 Entry, totalled 7.8 feet in length and were mainly of hard and dull coal with bright and soft bands. The sequence of samples 948-953 from 102 Panel, 6 Entry, South, were of mostly hard to very hard dull coal with a few bright bands. Figure 3-1 shows the locations of these samples.

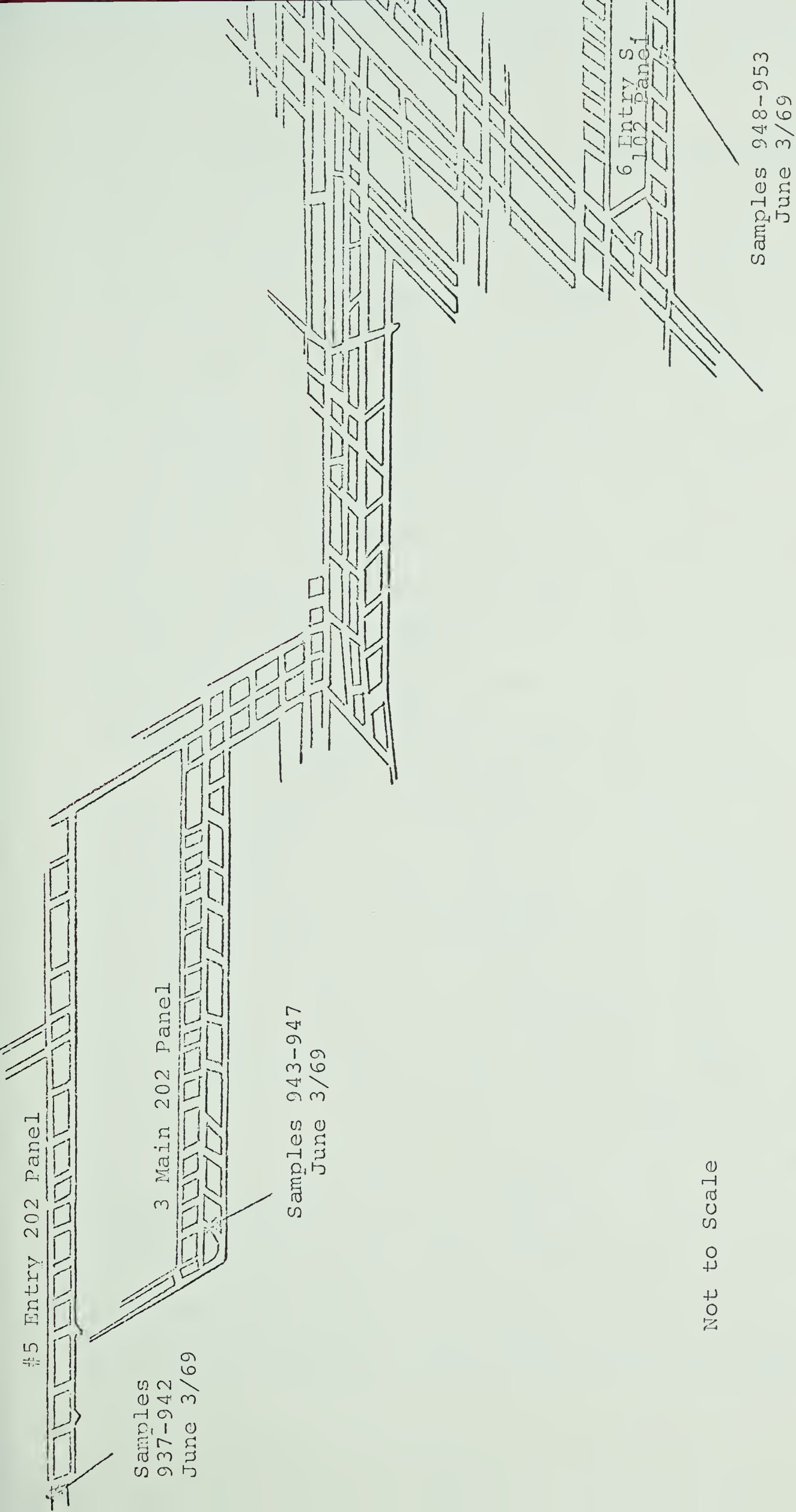


Figure 3-1. Location of Samples - Balmer West, Balmer North

On June 4, 1969, a visit was made to Coleman Collieries Limited, and samples were taken from two locations in the Vicary Creek Mine from B Level. Regionally the structural conditions of the Crowsnest district also apply at the Vicary Creek Mine. The coal of the Vicary Creek Mine is medium to low volatile bituminous in rank. Generally coal from the Vicary Creek Mine is dull and ranges from hard to very hard with a few bright and soft bands as in samples 956 and 957. Samples 954-958 from one section were cut from No.3 Panel Belt Road about 730 feet from the top end. The sequence of Samples 958-962 was cut from No.1 Panel, Gob area, from both the high and low sides. Figure 3-2 shows the locations where samples were taken from this mine.

A visit was made on June 5, 1969 to Canmore Mines Limited, and samples were cut from the Wilson seam. Coal at Canmore is also of Lower Cretaceous age and the structure of the Canmore Basin has been described by Wilson as an asymmetrical syncline. Much shearing action took place within the coal seams during the folding of the coal basin, as they are the weakest layers in the syncline. Wilson noted that great variations in the amount of movement and deformation are shown in the seams; in some places the coal shows its original banding and cleats, whereas in others it is so finely fragmented that none of the original structure remains. This range of textures was obvious in the samples obtained from the Wilson seam. The coal rank of this seam is mainly

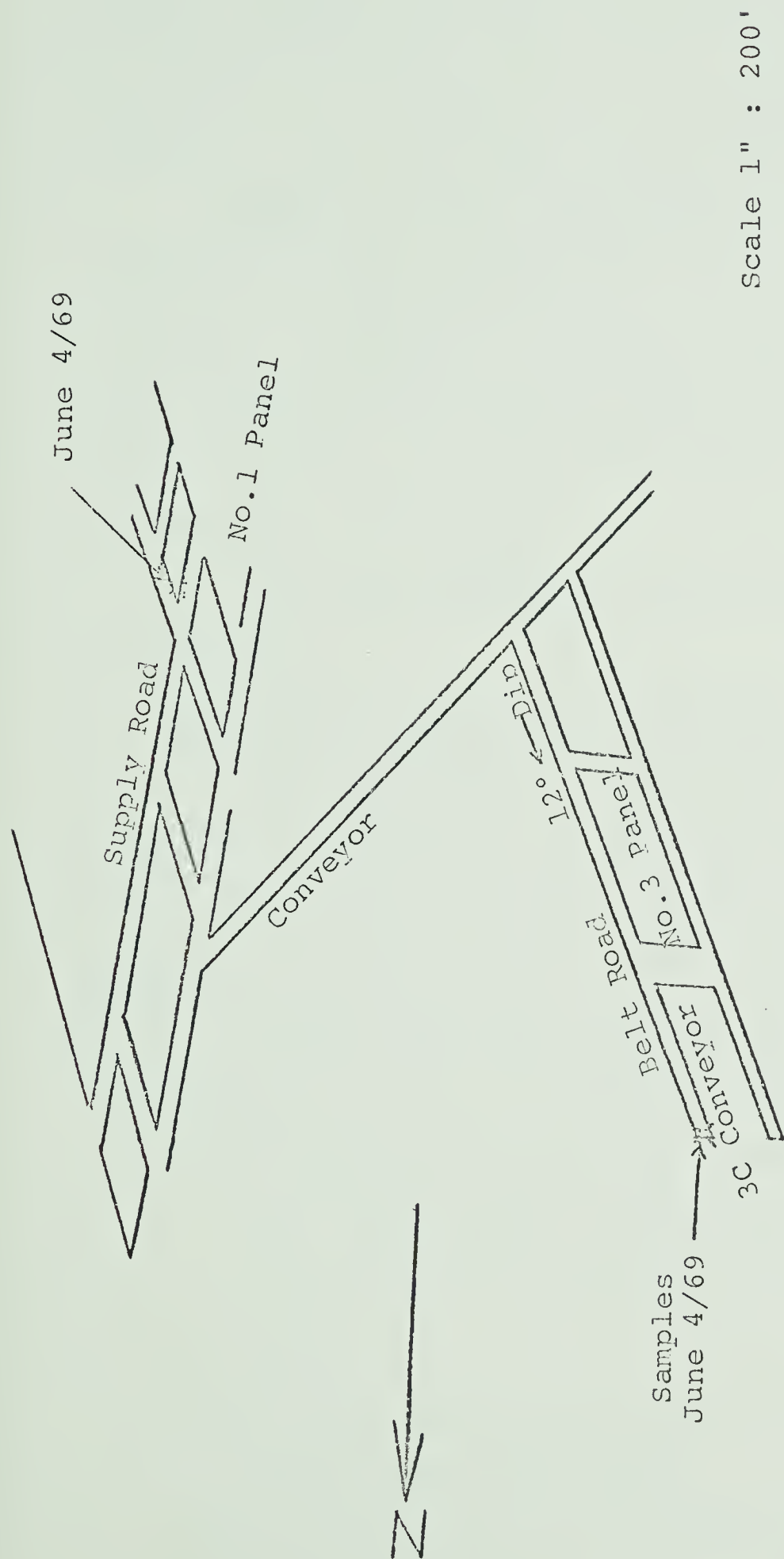


Figure 3-2. Location of Samples, B Level - Vicary Creek

semi-anthracite with a few bands of low volatile bituminous. Samples 963-966 were taken from the Pitch below #2 Gangway and Samples 967-973 were obtained in 9 x-cut off 48 Slope. Figure 3-3 shows the locations of these samples.

Samples 974-994 were received on February 23, 1970 from Canmore Mines Limited (all of them from the Wilson seam). Figure 3-4 shows the locations of the samples. The mine staff reported that Sample No. 986, which was taken from 47 Slope, 14 x cut, is from a face where a minor outburst had occurred the year before.

The sample numbers, locations and analyses are shown in Table 3-1.

2. Laboratory Preparation of Samples

The coal samples from the mines were first crushed to about -1/2 inch and then passed through a disc pulverizer for further size reduction, the coal being surrounded by a nitrogen atmosphere during grinding to prevent oxidation.

Samples were then divided by screening into portions having the following size ranges (Taylor Mesh):-

- For apparent sorption capacity by volume, -100 +200 and -200 +0 mesh. (Composite samples from the Balmer and Vicary Mines and Samples 963-973 from the Wilson Seam).
- For total sorption by weight, -65 mesh. (Certain samples from each seam).
- For ΔP measurements, -32 +60 (all samples), +10, -10 +32, -32 +100, -100 +325, -325 +0 (Samples 974-994 from the Wilson Seam).

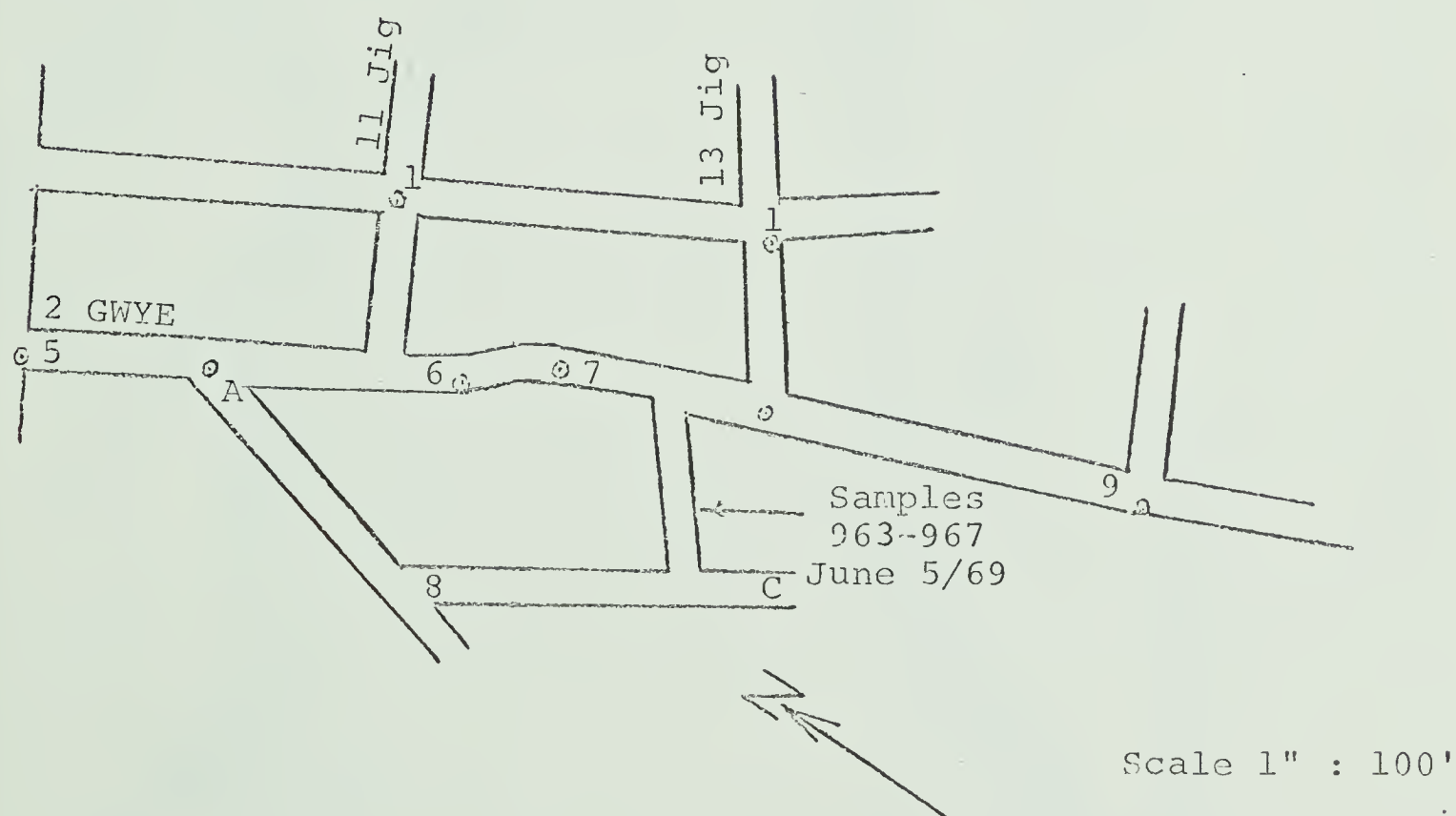
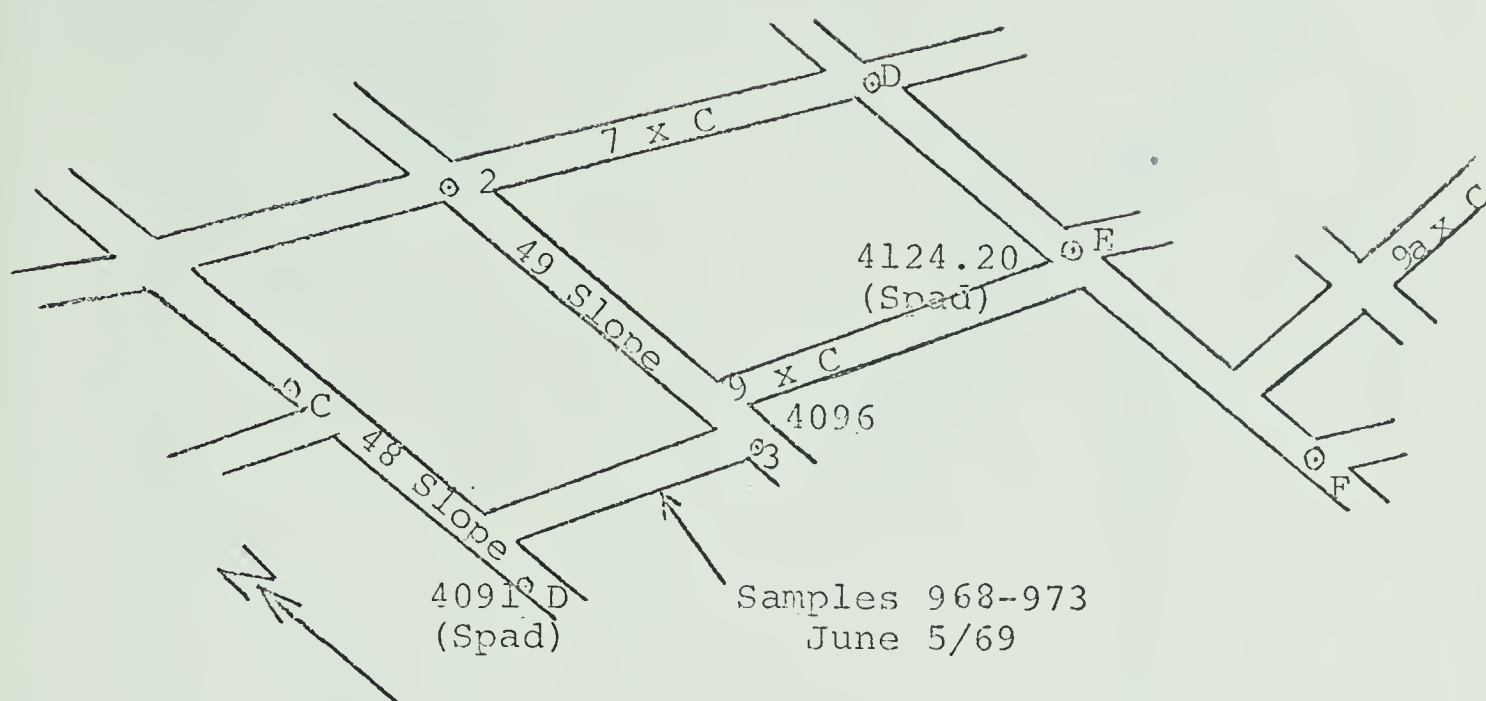


Figure 3-3. Location of Samples, Wilson Seam - Cannore

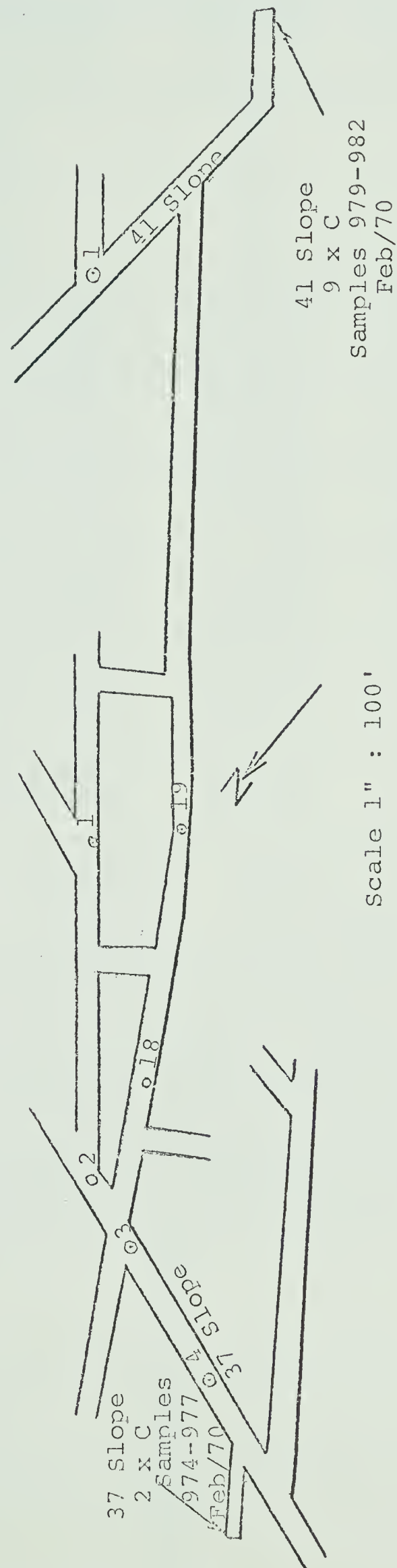
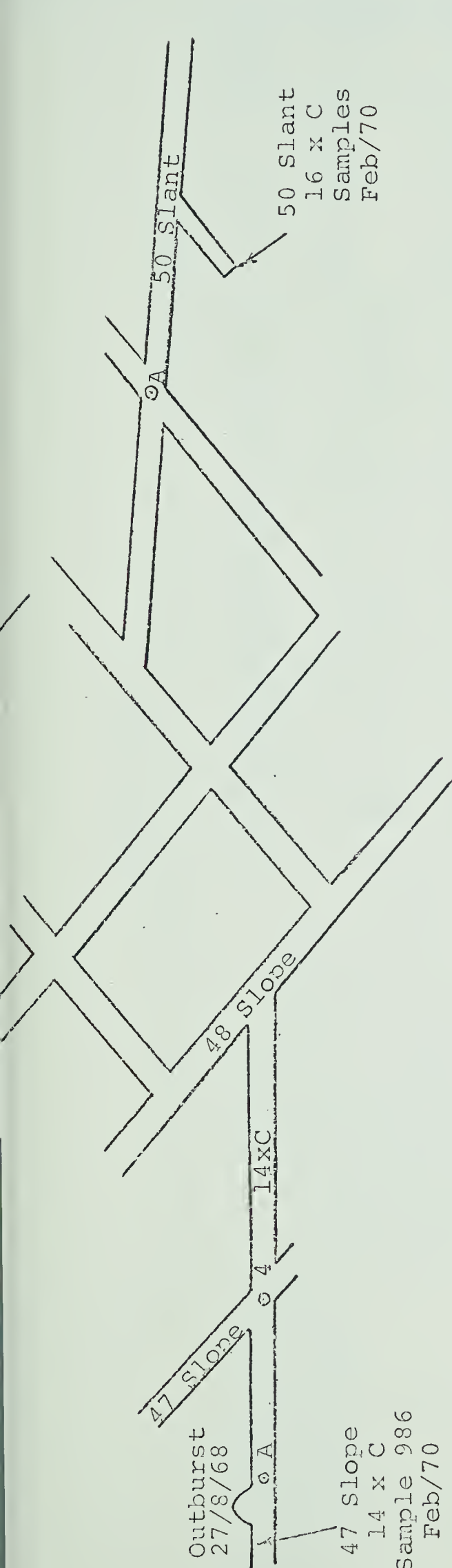


Figure 3-4. Location of Samples, Wilson Seam - Canmore

TABLE 3-1

Proximate Analysis and Apparent Specific Gravity of the Coal Samples

Date	Mine	Seam	Location	Sample No.	Average %			D.a.f. F.C.	Rank	App. Sp. Gr.
					Moist.	V.M.	Ash			
Jun 3/69	Balmer North	Balmer West	Face 5 Entry 202 Panel	937	0.13	16.15	24.25	59.47	Low Vol. Bit.	1.272
			-from roof to 1.0'	938	0.37	16.62	9.55	73.46	"	1.295
			-from roof 1.0' to 2.4'	939	0.30	16.87	7.21	75.62	"	1.319
			-from roof 2.4' to 4.0'							
			3 Main 202 Panel 2 Entry							
			-from roof to 0.8'	943	0.37	15.63	32.64	51.36	Med. Vol. Bit.	1.396
			-from roof 0.8' to 2.1'	944	0.25	15.31	12.17	72.27	Low Vol. Bit.	1.345
			-from roof 2.1' to 4.0'	945	0.23	15.80	7.13	76.84	"	1.481
			-from roof 4.0' to 6.0'	946	0.12	14.01	13.71	72.16	"	1.350
			-from roof 6.0' to 7.8'	947	0.04	19.14	10.24	70.58	"	1.335
			102 Panel 6 Entry S.							
			-from roof to 0.8'	948	0.29	14.99	40.73	43.99	Med. Vol. Bit.	1.495
			-from roof 0.8' to 2.2'	949	0.30	13.96	29.87	55.87	Low Vol. Bit.	1.501
Jun 4/69	Vicary	B Level	-from roof 2.2' to 3.8'	950	0	17.65	11.67	70.68	"	1.380
			-from roof 3.8' to 5.6'	951	0.31	17.76	8.54	73.39	"	1.337
			-from roof 5.6' to 7.0'	952	0.16	17.99	8.53	73.32	"	1.440
			-from roof 7.0' to 9.0'	953	0.24	11.85	11.93	70.98	"	1.395
			No. 3 Panel belt road 730'							
			from top end							
			-from roof to 0.7'	954	0.34	18.12	8.99	72.55	"	1.345
			-from roof 0.7' to 2.2'	955	0.35	16.13	9.64	73.88	"	1.373
			-from roof 2.2' to 3.4'	956	0.33	21.65	2.98	75.04	Med. Vol. Bit.	1.255
			-from roof 3.4' to 5.4'	957	0.28	18.20	32.13	49.39	"	1.342
			-from roof 5.4' to 7.4'	958	0.33	20.09	14.88	64.70	"	1.364
			No. 1 Panel supply road							
			Gob area high side							
			-from roof 13.0' to 15.0'	959	0.25	20.67	11.88	67.20	"	1.305
			-from roof 15.0' to 18.0'	960	0.25	19.87	20.88	59.00	"	1.257
			No. 1 Panel low side							
			-from 7.0' to 9.5'	961	0.33	23.38	9.22	67.07	"	1.385
			-from 9.5' to 12.0'	962	0.26	20.48	15.46	63.80	"	1.412

TABLE 3-1 (cont'd)

Date	Mine	Seam	Location	Sample No.	Average %			D.a.f. F.C.	Rank	App. Sp.Gr.
					Moist.	V.M.	Ash			
Jun 5/69	Canmore	Wilson	Pitch below #2 Gang	963	0.21	12.10	5.09	82.60	Semi-Anth.	1.318
			-from roof to 1.5'	964	0.13	19.94	6.79	73.14	Low Vol.Bit.	1.305
			-from roof 1.5' to 3.1'	965	0.29	12.04	13.31	74.36	Semi-Anth.	1.350
			-from roof 3.1' to 4.9'	966	0.39	10.42	4.47	84.72	"	1.305
			-from roof 4.9' to 6.0'	967	0.32	12.13	2.57	84.98	"	1.284
			-from roof 6.0' to 8.0'							
			9xC off 48 Slope low side							
			-from roof to 0.5'	968	0.43	12.06	8.48	79.03	"	1.335
			-from roof 0.5' to 3.0'	969	0.37	10.94	3.53	85.16	"	1.345
			-from roof 3.0' to 4.4'	970	0.34	7.53	27.57	64.56	"	1.328
Feb 23/70	Canmore	Wilson	-from roof 4.4' to 6.2'	971	0.28	10.38	5.28	84.06	"	1.328
			-from roof 6.2' to 7.5'	972	0.16	11.77	6.12	81.95	"	1.342
			-from roof 7.5' to 9.0'	973	0.39	9.69	7.65	82.27	"	1.345
			37 Slope 2xC #2EGWY							
			-bet. 9'-floor from roof	974	-	-	-	-		
			-bet. 6' to 9' from roof	975	0.20	10.41	7.58	81.81	"	87.7
			-bet. 0' to 3' from roof	976	0.36	10.48	13.38	75.78	"	88.2
			-bet. 3' to 6' from roof	977	0.27	11.85	4.10	83.78	"	87.9
			12 Slope #2EGWY							
			-bet. 4' to 6' from roof	978	0.37	10.31	7.04	82.28	"	89.0
			41 Slope 9xC							
			-bet. 0' to 3' from roof	979	0.23	10.08	7.49	82.20	"	89.0
			-bet. 3' to 6' from roof	980	0.22	11.18	5.11	83.49	"	88.4
			-bet. 6' to 9' from roof	981	0.43	10.37	6.56	82.64	"	88.8
			-bet. 9' to 12' from roof	982	0.33	10.38	2.84	86.45	"	89.3
			12 Slope #2EGWY							
			-bet. 0' to 2' from roof	983	0.31	11.34	4.09	84.26	"	88.0
			-bet. 2' to 4' from roof	984	0.30	10.17	3.35	86.18	"	89.2
			-bet. 6' to 8' from roof	985	0.33	10.74	6.66	82.27	"	88.5
			47 Slope (outburst)	986	0.57	11.28	9.27	78.94	"	87.7

TABLE 3-1 (cont'd)

Date	Mine	Seam	Location	Sample No.	Average %			D.a.f. F.C.	Rank	App. Sp.Gr.
					Moist.	V.M.	Ash			
Feb 23/70	Canmore	Wilson	50 Slant 17xC Joy miner, middle	987	0.38	11.31	3.80	84.57	Semi-Anth.	
			50 Slant 17xC Joy miner, middle	988	0.39	12.10	4.32	83.19	"	
			50 Slant (LN.2) middle	989	0.34	11.41	3.03	85.22	"	
			50 Slant (LN.2) middle	990	0.22	15.56	5.73	78.49	Low Vol.Bit.	
			50 Slant 17xC Joy miner,	991	0.35	15.47	4.78	79.40	"	
			50 Slant (LN.2)	992	0.41	11.50	3.38	84.71	Semi-Anth.	
			50 Slant 17xC Joy miner, bottom	993	0.31	10.25	5.39	84.05	"	
			50 Slant (LN.2) bottom	994	0.22	10.11	2.22	87.45	"	

Proximate analyses of portions of each of the ground coal samples were carried out by K. Hartung, Technician, Department of Mining and Metallurgy.

The samples were secured in plastic bags as they were taken from the working faces. After grinding and screening the various size ranges of the samples were again secured in plastic bags, and surrounded by a nitrogen atmosphere to prevent oxidation. Composite samples were prepared for certain tests to represent the whole section of a seam. This was done for certain size ranges, by taking 100 grams per foot of length from each sample in that section, and then combining these portions to produce the composite samples.

4. ΔP Index Measurements

The ΔP index was evolved by Ettinger and has been used in France and Belgium and other countries to obtain a measure of the rate of desorption under standard conditions and as an indirect means of classifying structure. The apparatus for measuring the ΔP index in the Department of Mining and Metallurgy was made by Singh to the same dimensions as the ΔP apparatus designed by CERCHAR (which is slightly modified from the equipment designed by Ettinger). The apparatus is constructed to test 8 samples at a time.

Briefly, for the standard ΔP test, 3 gm portions of coal of -32 +60 mesh size are first degassed for 1 1/2 hours by means of a vacuum pump. The samples are then saturated

with helium for 10 minutes at exactly one standard atmosphere of pressure, and then connected, one at a time, with a manifold of known volume which has been evacuated before each sample is connected to it. The pressure in the manifold caused by the release of helium is measured as the height of mercury in a connected manometer after few seconds and is recorded as P_1 (mm of mercury). This indicates the volume of the interstitial space in each case, because helium is not sorbed by coal. The samples are again evacuated for 1 1/2 hours and then saturated with methane at one standard atmosphere of pressure. They are again connected with the manifold, one after another, the manifold being evacuated before each sample is tested, and the pressure shown by the manometer after 10 seconds and after 60 seconds (P_2 and P_3 in mm of mercury respectively) is noted.

The following values are calculated:

$$P_{0-10} = P_2 - P_1 \text{ (in mm of mercury)}$$

$$P_{10-60} = P_3 - P_2 \quad "$$

$$P_{0-60} = P_3 - P_1 \quad "$$

The same procedure was used to measure a ΔP index for other size ranges of coal from the Wilson Seam in order to study the relations between ΔP indices and coal particle sizes and so indirectly to classify the coal structure. The particle sizes used for this purpose were as follows,-

+10, -10 +32, -32 +100, -100 +325 and -325 +0 mesh.

Determinations to measure the ΔP index were carried out on two or three portions from each sample or from each size range of certain samples. Results of the ΔP tests are shown and discussed in Chapter IV.

5. Volumetric Method for Measuring Apparent Sorption Capacity

A volumetric method for determining the sorption capacity for methane and carbon dioxide has been described by Singh. For the current series of tests two sets of equipment were used, following the same procedure outlined by Singh, the only difference being in the size of coal fragments used. Composite samples from the Balmer North, Vicary Creek and Canmore mines were used. Two ranges of size, -100 +200 mesh and -200 +0 mesh, were tested.

To carry out the test a portion of 6.5 grams was placed in a cell and evacuated for 45 minutes and then charged with methane at 50 psig at 21-24°C for 6 to 24 hours to attain equilibrium. Then the gas was released into a burette, displacing mercury. The mercury level in the burette was continually readjusted or leveled to keep the gas at atmospheric pressure by use of a connected leveling bulb. The volume of desorbed gas was recorded continually until desorption was completed. The free volume in the cell (dead volume), including the volume of gas compressed in pores, was determined by evacuating the portions and charging with helium gas at 50 psig for 15 minutes and then releasing

the volume of helium into the burette at atmospheric pressure. The difference between the volumes of methane and helium released represented the amount of desorbed gas (because helium was only compressed in the intergranular spaces and pores but not sorbed). The same procedure of evacuation, charging and releasing of gas was used on the same sample when measuring desorption of carbon dioxide. The results of the volumetric method determinations are shown in Chapter V.

6. Gravimetric Method for Measuring Total Sorption Capacity

Gravimetric determinations of total sorption capacity were carried out in apparatus made to similar dimensions (with slight modifications) as the apparatus developed and described by Daines for the Mining Research Establishment of the National Coal Board. The apparatus was used to measure the sorption of gas by powdered coal in the pressure range of 0 to 600 psig. The design of the apparatus allows tests to be carried out through the temperature range of 4.4°C to 54°C.

The principle of the gravimetric method may be described briefly as follows, - A known volume of powdered coal, determined from its apparent specific gravity and weight, was placed in a weighed capsule which was then evacuated and reweighed. Gas was admitted to the sample, and after allowing equilibrium pressure to be attained the capsule was again weighed. Further amounts of gas were admitted at increasing pressures and the capsule weighed each time. In order to determine the amount of gas compressed in the space surrounding the coal sample (dead volume) the experiment was repeated using the same volume of non-adsorbing material instead of the coal sample.

The apparatus is shown in Figure 3-5, and a schematic layout is shown in Figure 3-6. Six sample holding capsules, Figure 3-7, were made of Dural (24S aluminum alloy) with a polished outside surface. They were tested with oil at pressures to 1000 psig without yielding to ensure safe performance when charged with gas. Each capsule was fitted with a small light-alloy needle valve. The capsules were connected to a common manifold to which was connected a standard pressure gauge (0-600 psig) and a barometrically compensated vacuum gauge. Needle valves are represented by V_1 , V_2 and V_3 , where V_1 is to control the inlet of gas to the manifold, V_2 connects to the vacuum gauge, and V_3 to the vacuum pump or outlet. Stainless steel tubing and compression couplings were used throughout.

The apparatus is housed in a temperature-controlled cabinet. A small fan, thermostat and 125 Watt lamp were connected with an electrical relay to provide uniform control of temperature in the cabinet. For cooling a chilled fluid was circulated from a refrigerating unit to a coil of copper pipe fixed on the back of the aluminum plate on which capsules, main manifold, pressure and vacuum gauges and thermostat were mounted. The refrigerated fluid was able to reduce the cabinet temperature to about 0°C. One-inch thick styrofoam insulation was used to line the inside of the cabinet.

A constant load type balance, having a maximum load of 200 grams, was used for weighing the capsules to 0.1 mg. A capsule can hold about 40 grams of powdered coal.

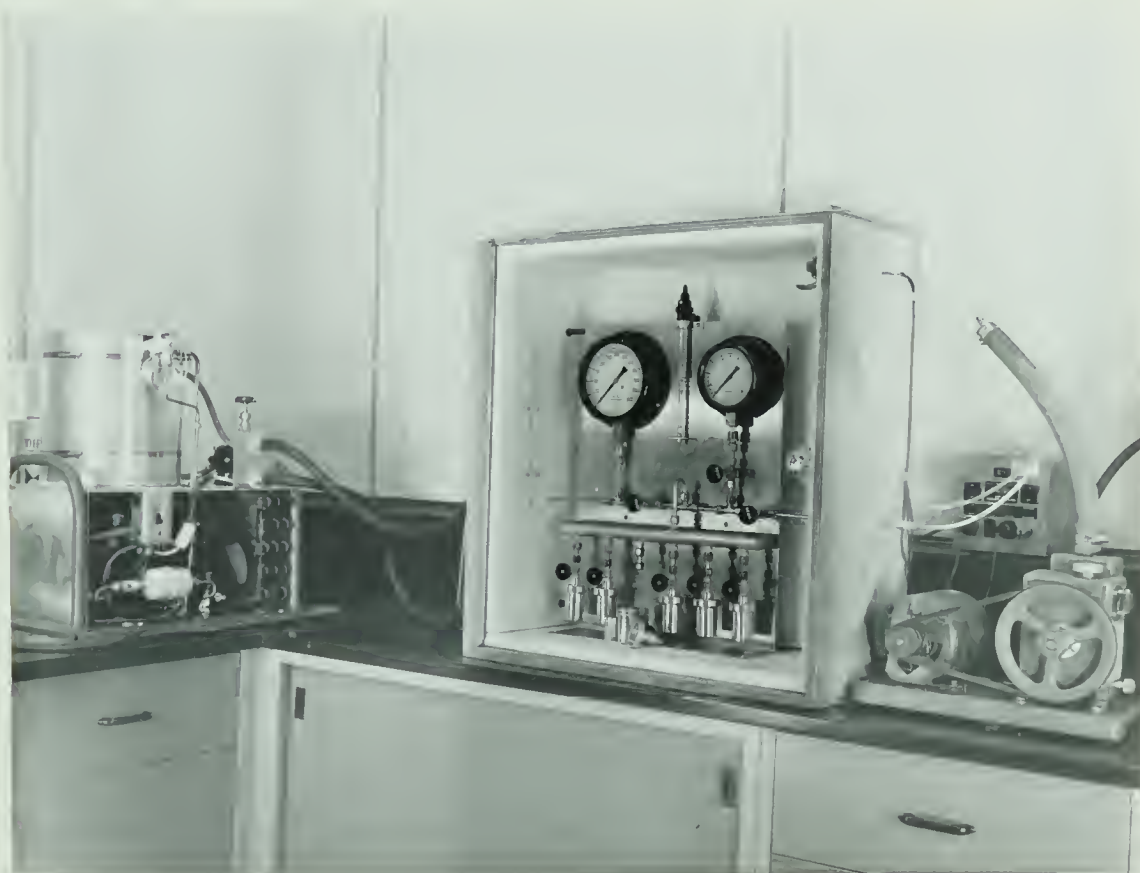
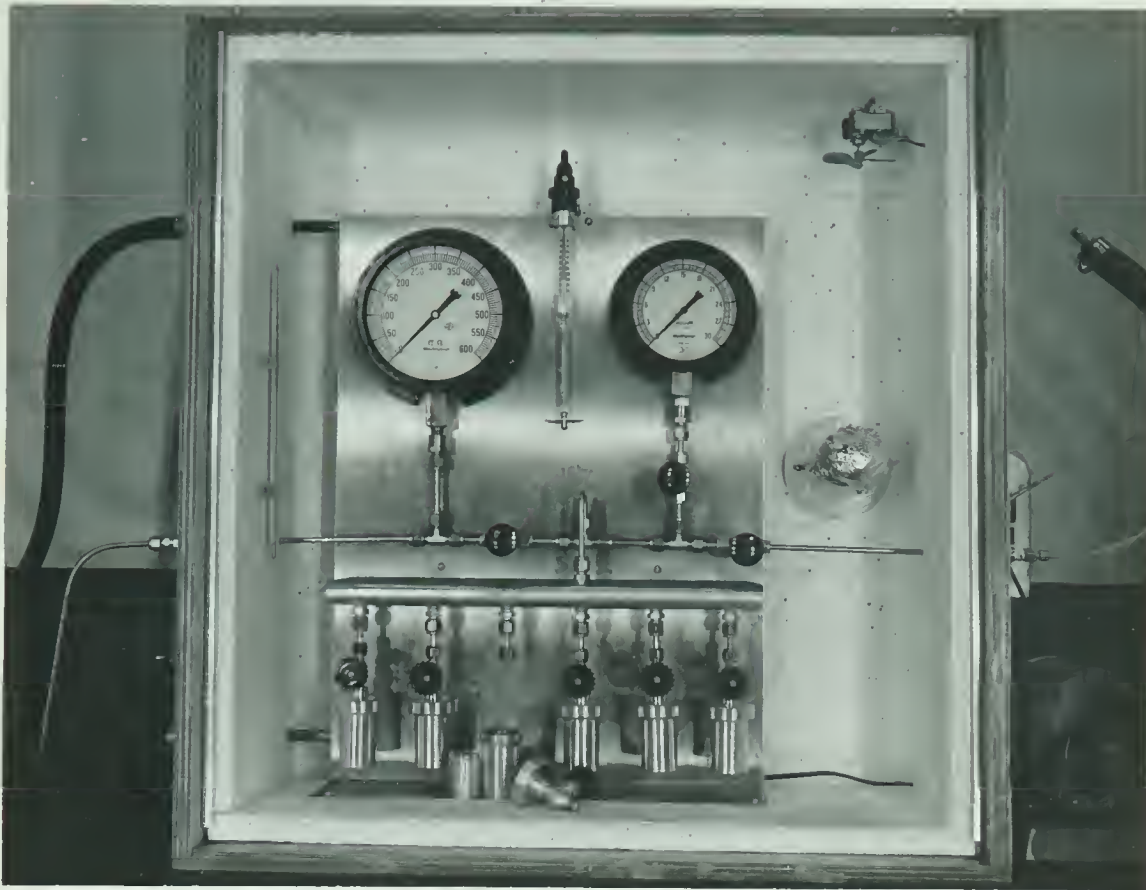


Figure 3-5. Sorption-By-Weight Apparatus

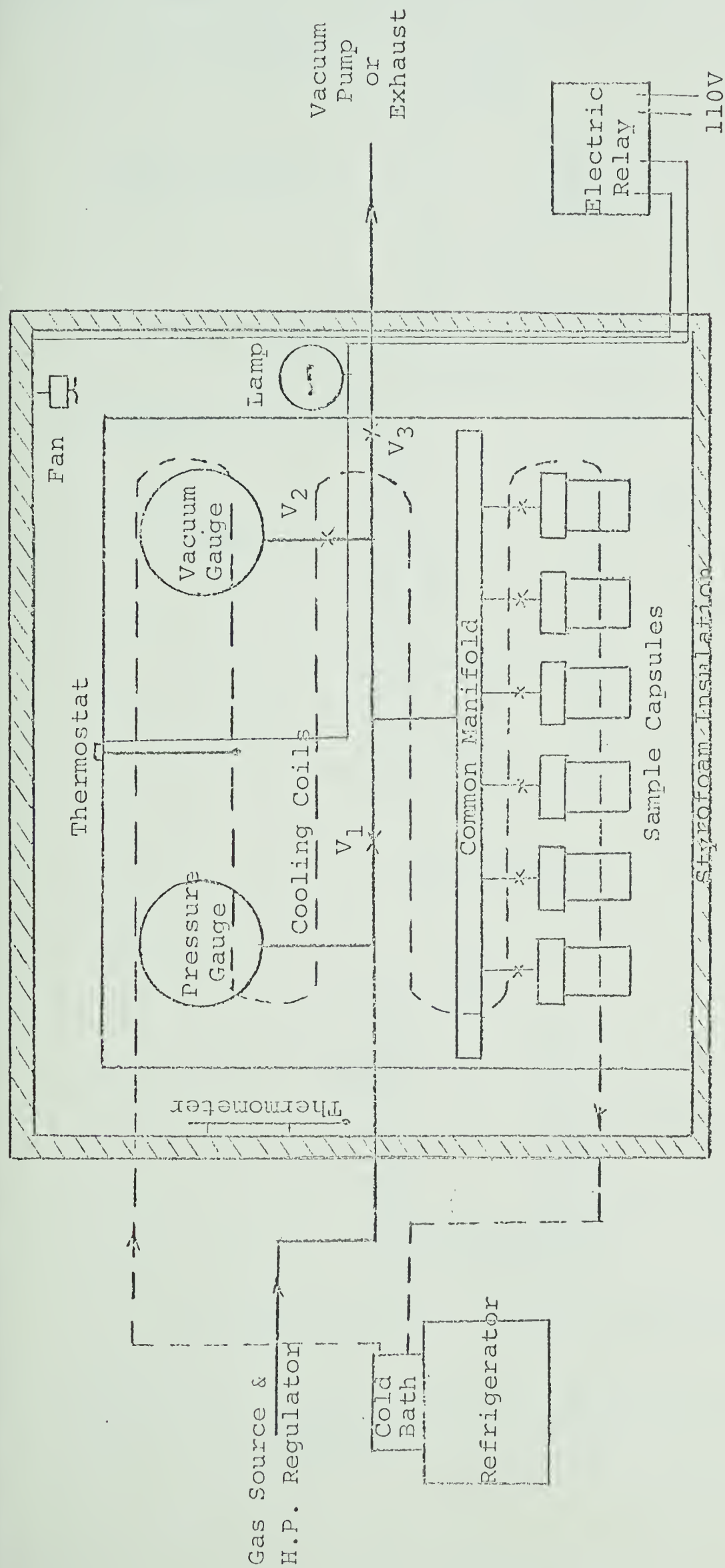
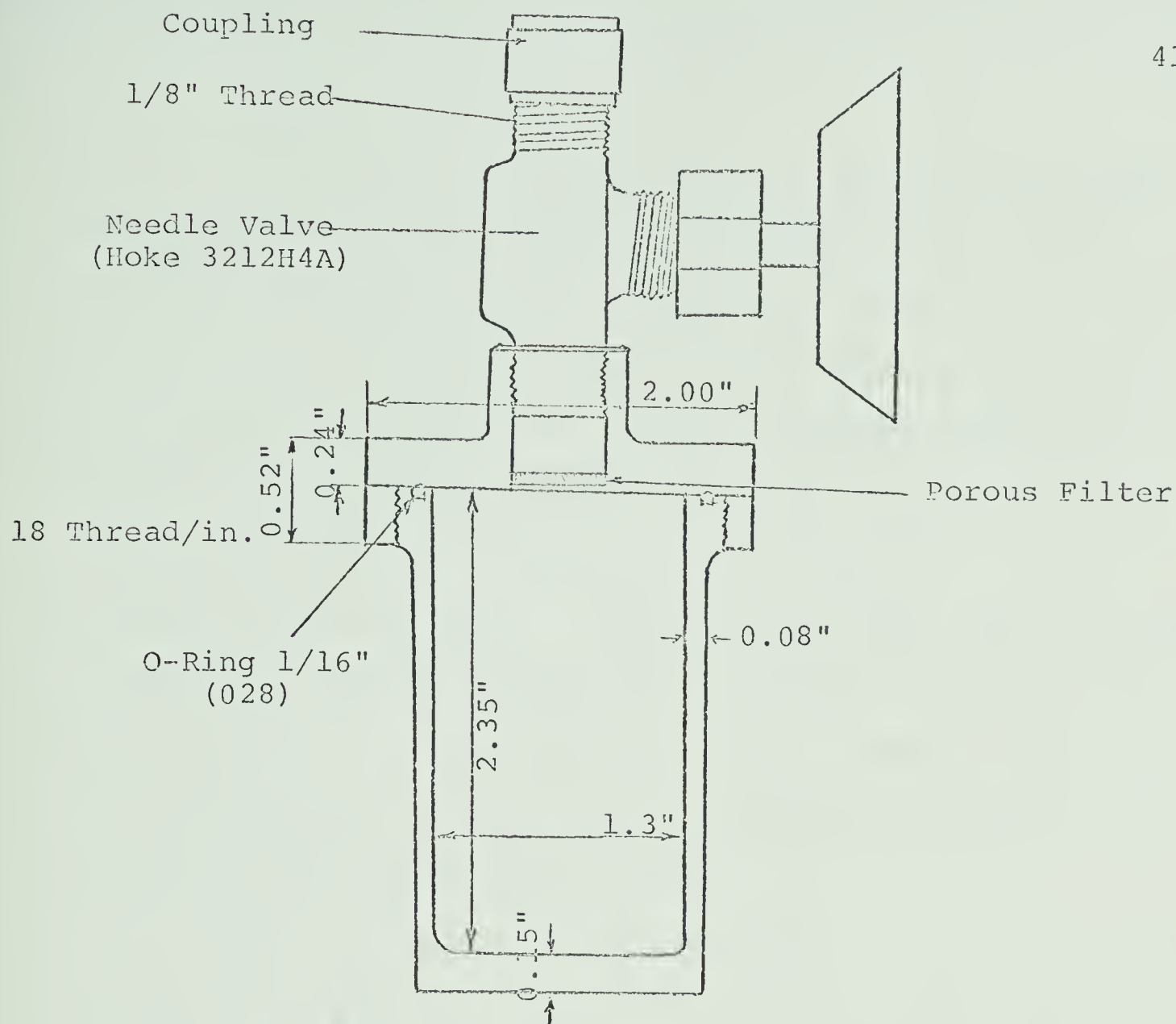
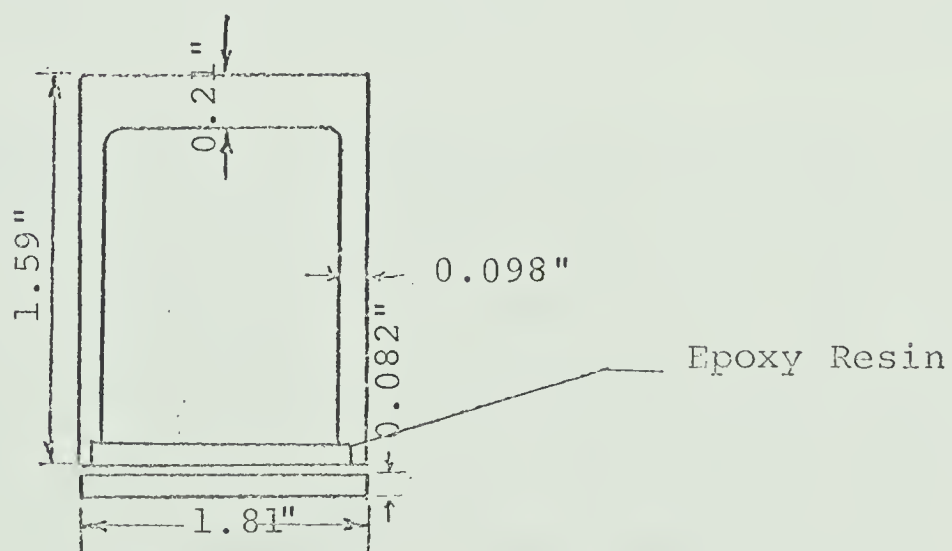


Figure 3-6. Diagram of Sorption-By-Weight Apparatus



Sample Capsule
Wt \approx 140 gm



Standard Equivalent Volume of 30.00 cc.

Figure 3-7. Details of Sample Capsule and Standard Volume Cylinder.

In order to enable the amount of gas contained by the free space in the capsules to be determined, several cylinders of non-adsorbing material were constructed, each having the same external volume as the volume of the coal portions used for the tests. These 'standard equivalent volumes' were hollow cylinders of Dural, sealed with epoxy (Figure 3-7) with an external volume of 30.00 c.c. and a weight of about 51 grams. After assembly they were carefully checked for leaks by weighing them, placing them in a cell and applying gas at 600 psig pressure for several hours and then reweighing. If there were no changes in weight it was considered that there were no leaks.

The sizes of coal particles used for the gravimetric sorption determinations were -65 +0 mesh for the main set of tests. For the tests to compare the volumetric and gravimetric methods composite coal samples of -200 +0 mesh size were used.

The apparent specific gravity of the different coals was determined by measurements on small lumps of about 20 grams weight from each sample. The lumps of coal were sealed with a thin layer of shellac and then weighed in air and then weighed again when suspended in water. The apparent specific gravity, which includes the effect of the porosity in the coal, was calculated as follows:

$$\text{App. sp. gr.} = \frac{W_A}{W_A - W_W}$$

where

W_A = weight in air

W_W = weight in water

The apparent specific gravity thus obtained includes the effect of the moisture content of the samples as tested. A small correction was required when using coal of different moisture contents. An increase of one percent moisture content had been shown by Daines to produce a similar increase in the apparent specific gravity; therefore when testing moistened samples the weight of portion required for a test was increased by one percent for each percent of moisture above the moisture content in the sample when the specific gravity determination was made.

The actual test procedure was carried out as follows: The bottom part of the capsule was cleaned and weighed. The portion weight was calculated from the volume required (30.00 cm^3) and the apparent specific gravity of that coal sample. A torsion balance (± 0.01 gram accuracy) was set to the required weight and the bottom part of the capsule filled to this weight for the first step of weighing (to save time). The bottom part of the capsule, which had been previously carefully weighed, and the contained coal was then placed on the constant-load balance to determine the weight of coal precisely. The bottom part of the capsule was cleaned very carefully with acetone, especially around the o-ring and the threads, and the threads of the top piece were also cleaned. The capsule was then assembled and connected to the apparatus.

After connecting the 6 capsules, valves V_1 and V_3 were closed, V_2 was opened, and the needle valves of the capsules were opened and the vacuum pump started. Valve V_3 was gradually opened so that the pressure in the system dropped slowly during evacuation. After the vacuum gauge indicator was constant (2-5 minutes), evacuation continued for 15 minutes. (As a check on the possible loss of moisture from the laboratory-stored coal by evacuation, on four occasions a few grams of coal particles from a capsule were tested for moisture content after sorption tests were completed, and they were all found to have the same moisture content as before evacuation - this indicates that no appreciable loss of moisture occurred during the 15 minute evacuation period.) After evacuation was completed, the capsule needle valves and valve V_3 were closed and the capsules removed and then weighed to the nearest 0.1 mg. The capsules were then reconnected to the apparatus, being careful to connect them to their respective unions because of small differences in the seating. The pipe system leading to the capsules was next re-evacuated rapidly for a minute. Valve V_3 was then closed and the gas was admitted carefully to the manifold by opening V_1 slowly until the vacuum gauge read zero. The capsule needle valves were then opened, admitting gas (methane, carbon dioxide or helium) to the samples. Additional gas had to be admitted to maintain pressure at the gauge while the gas was being sorbed until

equilibrium pressure had been attained. This normally took from 2 to 6 hours. Then the capsule needle valves were closed, and the capsules were removed and weighed.

The above procedure was repeated at increasing pressures (50, 100, 200, 300, 400, 500 and 600 psig) using the main pressure gauge (V_2 being closed). Two hours were allowed for equilibrium to take place and after that the capsules were weighed; then they were reconnected and gas was admitted for another two hours and then the capsules were weighed again. When the weight was constant it was assumed that equilibrium was attained. It was found that at 50 psig and higher pressures two hours were sufficient to attain equilibrium. Minor leaks (if any) were recorded for one minute (by using a stop watch) during weighing and then the original weight was corrected. Any considerable leak could be traced by painting the joints with leak-detecting fluid.

To determine the quantity of gas compressed in the space surrounding the coal portion, it was necessary to repeat the sorption test using the same volume of non-adsorbing material. The coal was replaced in the capsules by the standard equivalent volumes (30.00 cm^3) and the experimental procedure was repeated as with the coal samples. A period of only about 20 minutes was necessary for the capsules to attain temperature equilibrium. One set of measurements for each capsule at the usual test pressures

between 0 to 600 psig for every gas (CH_4 , CO_2 , He_2) was required at each test temperature (4.4, 21, 38 and 54°C). Details of the calculation of total sorption capacity are shown in Appendix.

Certain precautions were necessary when weighing to eliminate errors:

- a) It was always necessary to allow the capsules to reach room temperature before weighing. This was done by placing them on an aluminum block (heat sink) for 10 minutes.
- b) Before each weighing the capsules were wiped by tissues to eliminate any traces of finger grease and dirt.
- c) A standard 'dummy' capsule was weighed each time, following the same routine, to compensate for air buoyancy changes due to any change in barometric pressure.

The moisture contents of coal samples were varied by exposing them to an atmosphere of constant relative humidity in a metallic desiccator inside a temperature-controlled oven (86°F) for about 48 hours. Saturated solutions of potassium carbonate or ammonium nitrate were placed in a pan in the desiccator in order to provide constant relative humidity. Small portions from the moistened coal were taken to determine accurately the moisture contents. For moisture contents of more than 2% it was necessary to wet the coal samples by a spray of water and then mix each sample carefully several times while keeping it in the metallic

desiccator inside the temperature controlled oven, and then small quantities were taken to determine accurately the moisture content.

The following precautions were taken to prevent any loss in moisture content when testing moistened coal, -

- a) Capsules were filled as rapidly as possible to avoid any loss in moisture content of the sample.
- b) Evacuation continued only for one minute after complete opening of valve V_3 to avoid removal of moisture by evacuation.

In order to obtain dry coal, the portions inside the capsules were evacuated for about 30 minutes while the cabinet temperature was set to 50°C.

Duplicate determinations were made on each sample for each given test condition. Results are shown and discussed in Chapter V.

CHAPTER IV

RESULTS AND DISCUSSION OF ΔP MEASUREMENTS1. General

As previously noted, the ΔP test procedure has been developed to measure under standardized conditions the initial rate of desorption, which indicates the coal's capacity for rapid release of firedamp. Table 4-1 shows ΔP_{0-10} and ΔP_{0-60} values for -32 +60 mesh fragments from the Balmer North, Vicary B and Canmore Mines. Two or three portions from every sample were tested to check the accuracy of the procedure. The table shows that the ΔP values of the portions generally agree within 1 or 2 units (mm of mercury). This is within the same range of accuracy as obtained by the French investigators and by Singh.

2. Relation Between ΔP_{0-10} and ΔP_{0-60}

The ΔP_{0-10} values from Table 4-1 are plotted against the ΔP_{0-60} values in Figure 4-1 to test their correlation. The plot shows a general correlation between the two indices but there is considerable scatter in the values. Belin et al (1964) regarded the ΔP_{0-60} as the most significant index. Since the ΔP_{0-60} and ΔP_{0-10} indices have the same general relationship, the ΔP_{0-60} index is the only one to be considered in subsequent discussion of ΔP measurements.

TABLE 4-1

Standard ΔP Index (-32 +60 mesh) for Samples
from Balmer N, Vicary B, and Canmore Mines

Mine	Seam	Location	Sample No.	ΔP_{0-10}	ΔP_{0-60}	Average ΔP_{0-60}
Balmer N	Balmer W	Face 5 Entry 202 Panel				
		-from roof to 1.0'	937	12, 14, 12	28, 28, 26	27
		-from roof 1.0' to 2.4'	938	5, 6, 4	16, 16, 16	16
		-from roof 2.4' to 4.0'	939	8, 6	18, 16	17
		202 Panel 2 Entry				
		-from roof to 0.8'	943	10, 8, 10	20, 20, 22	21
		-from roof 0.8' to 2.1'	944	12, 14, 10	24, 24, 22	23
		-from roof 2.1' to 4.0'	945	20, 18, 18	32, 32, 32	32
		-from roof 4.0' to 6.0'	946	6, 4, 8	18, 14, 16	16
		-from roof 6.0' to 7.8'	947	12, 10, 10	20, 20, 20	20
Vicary B	-	102 Panel 6 Entry South				
		-from roof to 0.8'	948	12, 10	20, 17	18.5
		-from roof 0.8' to 2.2'	949	6, 6, 6	12, 12, 12	12
		-from roof 2.2' to 3.8'	950	10, 7, 6	16, 14, 12	14
		-from roof 3.8' to 5.6'	951	6, 6, 4	14, 14, 11	13
		-from roof 5.6' to 7.0'	952	22, 20, 18	30, 26, 26	27
		-from roof 7.0' to 9.0'	953	10, 8	18, 16	17
		No. 3 Panel belt road 730'				
		from top end				
		-from roof to 0.7'	954	0, 0	3, 4	3.5
		-from roof 0.7' to 2.2'	955	4, 2	12, 10	11
		-from roof 2.2' to 3.4'	956	8, 6	18, 17	17.5
		-from roof 3.4' to 5.4'	957	9, 10, 11	17, 17, 18	17
		-from roof 5.4' to 7.4'	958	3, 1, 0	7, 5, 5	6

TABLE 4-1 (cont'd)

Mine	Seam	Location	Sample No.	ΔP_{0-10}	ΔP_{0-60}	Average ΔP_{0-60}
Vicary B	-	No.1 Panel supply road Gob area high side	959	3,1	8,11	9.5
		-from roof 13.0' to 15.0'	960	2,0	10,8	9
		-from roof 15.0' to 18.0'				
Canmore	Wilson	No.1 Panel supply road Gob area low side	961	2,2,2	8,10,8	9
		-from 7.0' to 9.5'	962	4,2,2	8,6,7	7
		-from 9.5' to 12.0'				
		Pitch below #2 Gang	963	10,12,10	25,26,24	25
		-from roof to 1.5'	964	6,5,2	14,13,12	13
		-from 1.5' to 3.1'	965	2,2,0	9,9,8	9
		-from 3.1' to 4.9'	966	12,11	23,21	22
		-from 4.9' to 6.0'	967	10,11	22,21	21.5
		-from 6.0' to 8.0'				
		9xC off 48 Slope low side				
		-from roof to 0.5'	968	20,20,18	34,34,32	33
		-from 0.5' to 3.0'	969	13,10,8	21,19,18	20
		-from 3.0' to 4.4'	970	20,16,15	34,30,30	31
		-from 4.4' to 6.2'	971	6,4,3	12,12,11	12
		-from 6.2' to 7.5'	972	13,11,11	27,24,23	24
		-from 7.5' to 9.0'	973	6,5,3	16,16,14	15
		37 Slope 2xC #2EGWY Sample				
		-between 9'-floor from roof	974	16,16	32,33	33
		-bet. 6' to 9' from roof	975	16,14	32,30	31
		-bet. 0' to 3' from roof	976	8,6	28,27	27.5
		41 Slope 9xC sample				
		-between 0' to 3' from roof	979	6,7	27,28	27.5
		-bet. 3' to 6' from roof	980	8,8	24	24
		-bet. 6' to 9' from roof	981	6,6	24,22	23
		-bet. 9' to 12' from roof	982	2,8	26,26	26

TABLE 4-1 (cont'd)

Mine	Seam	Location	Sample No.	ΔP_{0-10}	ΔP_{0-60}	Average ΔP_{0-60}
Canmore	Wilson	12 Slope #2EGWY Sample	983	10, 10	23, 24	23.5
		-between 0' to 2' from roof	984	12, 9	24, 23	23.5
		-bet. 2' to 4' from roof	978	14, 15	32, 32	32
		-bet. 4' to 6' from roof	985	12, 15	26, 28	27
		-bet. 6' to 8' from roof				
		47 Slope (outburst seam - mine information)	986	21, 21	45, 45	45
		50 Slant 17xC Day mine middle	987	6, 8	19, 22	20.5
		50 Slant 17xC Joy mines middle	988	15, 10	28, 26	27
		50 Slant (LN.2) middle	989	10, 9	25, 24	24.5
		50 Slant (LN.2) middle	990	7, 6	21, 21	21
		50 Slant 17xC Joy mines	991	0, 0	16, 19	17.5
		50 Slant (LN.2)	992	10, 8	22, 20	21
		50 Slant-17xC Joy mines bottom	993	2, 2	14	14
		50 Slant (LN.2) bottom	994	4, 4	18, 16	17

3. Interpretation of the ΔP_{0-60} Values

Vandeloise (1966) proposed the following classification to indicate the degree of danger of Belgian coals to sudden outbursts of methane after he had studied the indices of several thousand samples.

TABLE 4-2

<u>ΔP_{0-60}</u>	<u>Susceptibility</u>
0-15	Not dangerous
15-30	Doubtful coal
30-45	Dangerous coal
>45	Very dangerous coal

Vandeloise, and also Belin (1966), have stated that to get a fair assessment of a seam's danger by using this classification a sufficient number of measurements (at least 100 samples) are required, well distributed over every working place.

A grouping of the ΔP indices for the 54 samples of Canadian coals shown in Table 4-1 is given in Table 4-3. The ΔP values of these samples ranged from 4 to 45.

TABLE 4-3

Summary of ΔP Values
(According to the Classification of Vandeloise)

Seam	$\Delta P < 15$	$15 < \Delta P < 30$	$30 < \Delta P < 45$	$45 < \Delta P < 60$	Total Number of Samples
Balmer W	3	10	1	-	14
Vicary B	7	2	-	-	9
Wilson	4	21	5	1	31

According to the classification of Vandeloise, the ΔP indices for most of the samples from the Balmer West seam are in the doubtful category, but according to the writer's knowledge there have been no sudden outbursts from this particular seam. Most ΔP values from the Vicary B seam lie in the category of "not dangerous coal". This agrees with present knowledge that no sudden outbursts have occurred in this seam. The Wilson seam samples generally show higher values of the ΔP index than those from Balmer West, and fall in the non-dangerous to dangerous categories.

According to the classification of Vandeloise, Sample No.986 from 47 Slope, Wilson seam, may be considered either a dangerous or a very dangerous coal (ΔP index of 45). It is worthy of mention here that this sample was taken from a face where a minor outburst occurred on August 27th, 1969, and its ΔP index was the highest in the writer's set of tests. The dip of the seam where the outburst occurred is about 15° . This area is located below the No.4 seam which had been mined some years before. It was found, when the plan of No.4 seam was superimposed over the plan of the Wilson seam, that the outburst occurred below the boundary of a pillar in No.4 seam (personal communication with T. Patching). The pillar of No.4 seam probably caused a higher than normal concentration of stresses in the area underneath it in the Wilson seam. Fissuring caused by the high stresses probably lead to the high ΔP value and together with the force of gravity and the pressure of sorbed gas caused the outburst.

Singh used an earlier classification of Vandeloise (1964) to estimate the degree of danger for samples from several Western Canadian mines (Upper Marsh and Wilson seams at Canmore, and Balmer #1 and Balmer North seams of Kaiser). Singh's values of ΔP ranged from 10 to 95 (the writer's values ranged from 4 to 45) and, according to the earlier classification of Vandeloise, most of his samples could be classified as doubtful coal, dangerous, and very dangerous coal. He also observed that his single ΔP measurement on a sample from the Wilson seam indicated highly dangerous coal although there had been no sudden outbursts in the seam to the time of completion of his thesis. Subsequently the small outburst previously noted occurred in this seam.

4. Relation of Rank to ΔP Index

Figure 4-2 shows the ΔP index against fixed carbon % (d.a.f.). The plot shows some indication that the ΔP index increases with increase of percentage of fixed carbon, i.e. coal rank, but the great scatter of the points in the figure indicates that variations in the structure of coal influence the ΔP index so much that the possible effect of rank is obscured.

Generally low rank high-volatile coals have more strength and offer more mechanical resistance to fracturing than bituminous coals with low volatile content (Alpern). Coal fissuring is thus indirectly related to the coal rank because low rank coal has more resistance for fracturing when the seam is subjected to tectonic or local stresses.

Consequently, for bituminous coals it is reasonable to expect some increase in ΔP indices with increase rank.

5. Study of ΔP in Connection with Fissuration

Table 4-4 shows ΔP measurements on different size ranges of the same samples. These sizes were obtained by screening so that they corresponded with the classes of fissuration as defined by Belin and Chiche. In the same table the fissuration classes were estimated from the ΔP measurements of different size ranges by using the procedure developed by Belin and Chiche, which has already been described in Chapter II. The values of ΔP from the table were plotted in several graphs to show the relation between size range and ΔP index, Figure 4-3 to Figure 4-8. These figures show that if a given coal is crushed more and more finely, the ΔP index at first reacts slightly to the size of particles and then increases abruptly, apparently when the particles become smaller than the average distance between fissures. This is a clear indication that ΔP index is linked to coal fissuration.

Table 4-4 shows that most of the samples from the Wilson seam lie in Fissuration Class III as defined by Belin. Class III of fissuration comprises the 0.50 - 0.16 size range, which is quite close to the standard ΔP index size range of 0.50 - 0.25 mm.

The ΔP indices of several samples have been plotted against particle size on a log-log scale in Figure 4-9. The

TABLE 4-4

ΔP Measurement of Different Size Ranges
 and Fissuration Class
 Canmore Mine - Wilson Seam

Sample No.	Size Range mm	ΔP_{0-10}		ΔP_{0-60}		Fiss. Class
		Indiv.	Mean	Indiv.	Mean	
974	>1.6	5,7	6	13,16	14.5	III
	1.6-0.5	6,6	6	16,16	16	
	0.5-0.16	16,14	15	35,32	33.5	
	0.16-0.05	44,44	44	72,76	74	
	<0.05	74,80	77	120,116	118	
975	>1.6	4,5	4.5	14,13	13.5	III
	1.6-0.5	4,6	5	13,14	13.5	
	0.5-0.16	15,13	14	33,32	32.5	
	0.16-0.05	46,46	46	76,74	75	
	<0.05	76,88	82	120,118	119	
976	>1.6	1,3	2	14,13	13.5	III
	1.6-0.5	4,2	3	14,16	15	
	0.5-0.16	8,8	8	32,32	32	
	0.16-0.05	40,44	42	68	68	
	<0.05	86,84	85	118,118	118	
979	>1.6	4,6	5	24,26	25	III
	1.6-0.5	8,8	8	26,26	26	
	0.5-0.16	12,11	11.5	42,37	40	
	0.16-0.05	50,52	51	92,88	90	
	<0.05	102	102	120	120	
980	>1.6	4,5	4.5	13,12	12.5	III
	1.6-0.5	5,4	4.5	16,12	14	
	0.5-0.16	10,10	10	30,28	29	
	0.16-0.05	44,42	43	94,90	92	
	<0.05	108,108	108	126,126	126	
981	>1.6	8,8	8	20,20	20	III
	1.6-0.5	8,6	7	22,18	20	
	0.5-0.16	8,10	9	28,30	29	
	0.16-0.05	56,58	57	90,94	92	
	<0.05	108,106	107	126,122	124	
982	>1.6	2,4	3	18,20	19	II
	1.6-0.5	6,12	9	30,32	31	
	0.5-0.16	10,10	10	32,32	32	
	0.16-0.05	58,60	59	102	102	
	<0.05	-	-	-	-	
983	>1.6	2,4	3	13,14	13.5	II
	1.6-0.5	6,5	5.5	19,23	21	
	0.5-0.16	14,14	14	34,36	35	
	0.16-0.05	52,52	52	98,92	95	
	<0.05	-	-	-	-	

TABLE 4-4 (cont'd)

Sample No.	Size Range mm	ΔP_{0-10}		ΔP_{0-60}		Fiss. Class
		Indiv.	Mean	Indiv.	Mean	
984	>1.6	4,3	3.5	9,8	8.5	III
	1.6-0.5	1,1	1	11,8	9.5	
	0.5-0.16	13,14	13.5	29,30	29.5	
	0.16-0.05	42,40	41	74,72	73	
	<0.05	110,108	109	122,120	121	
978	> 1.6	4,6	5	18,16	17	II
	1.6-0.5	11,9	10	23,21	22	
	0.5-0.16	14,12	13	31,28	30	
	0.16-0.05	50,48	49	84,82	83	
	<0.05	96,102	99	118,120	119	
985	>1.6	1,1	1	11,9	10	II
	1.6-0.5	9,7	8	16,17	16.5	
	0.5-0.16	21,22	21.5	39,42	40.5	
	0.16-0.05	58,56	57	90,86	88	
	<0.05	100,102	101	118,122	120	
986	>1.6	6,3	4.5	14,11	12.5	II
	1.6-0.5	11,8	9.5	22,19	20.5	
	0.5-0.16	26,22	24	46,48	47	
	0.16-0.05	88,88	88	112,114	113	
	<0.05	-	-	-	-	
987	>1.6	0,0	0	4,8	6	III
	1.6-0.5	0,0	0	8	8	
	0.5-0.16	12,14	13	28,30	29	
	0.16-0.05	32,35	33.5	64,66	65	
	<0.05	100,98	99	124,118	121	
988	>1.6	2,2	2	6,6	6	III
	1.6-0.5	2,1	1.5	10,6	8	
	0.5-0.16	10,7	8.5	24,21	22.5	
	0.16-0.05	36,40	38	98,108	103	
	<0.05	94	94	122	122	
989	>1.6	0	0	23,18	20	IV
	1.6-0.5	0,0	0	16,14	15	
	0.5-0.16	2,5	3.5	13,17	15	
	0.16-0.05	40,38	39	68,66	67	
	<0.05	-	-	-	-	
990	>1.6	3,2	2.5	13,10	11.5	II
	1.6-0.5	10,12	11	26,26	26	
	0.5-0.16	18,18	18	38,40	39	
	0.16-0.05	54,52	53	86,82	84	
	<0.05	98,100	99	122	122	
991	>1.6	3,4	3.5	6,10	8	II
	1.6-0.5	4,6	5	14,16	15	
	0.5-0.16	8,4	6	24,18	21	
	0.16-0.05	52,52	52	114,116	115	
	<0.05	-	-	-	-	

TABLE 4-4 (cont'd)

Sample No.	Size Range mm	ΔP_{0-10}		ΔP_{0-60}		Fiss. Class
		Indiv.	Mean	Indiv.	Mean	
992	>1.6	6,8	7	12,14	13	III
	1.6-0.5	6,6	6	13,12	12.5	
	0.5-0.16	13,10	11.5	29,27	28	
	0.16-0.05	48,54	51	78,82	80	
	<0.05	106,102	104	126,124	125	
993	>1.6	2,4	3	8,12	10	II
	1.6-0.5	4,2	3	16,16	16	
	0.5-0.16	10,8	9	22,22	22	
	0.16-0.05	34,33	33.5	60,60	60	
	<0.05	90,96	93	120,122	121	
994	>1.6	7,4	5.5	14,16	15	IV
	1.6-0.5	8,8	8	20,18	19	
	0.5-0.16	7,6	6.5	21,20	20.5	
	0.16-0.05	40,36	38	68,66	67	
	<0.05	84,88	86	126,122	124	

flat sections of the plots for some of the larger size portions suggest that ΔP values remain more or less constant when particle sizes are greater than the distance between fissures and the differences between ΔP values from one sample to another in these size ranges are dependent on fissuration. For particle sizes less than the average fissuration interval, changes in ΔP values are mainly influenced by size of particles (represented by the more or less straight parts of the curves). The figure also shows that for particle sizes less than about 0.05 mm the ΔP values of all samples from the Wilson seam are close in value to each other; this similarity of values probably indicates that nearly-total desorption has been accomplished at the end of the 60 second period and so the ΔP_{0-60} index does not indicate rate of desorption for very fine sizes.

CHAPTER V

RESULTS AND DISCUSSION OF SORPTION MEASUREMENTS

1. Apparent Sorption Capacity by the Volumetric Method

The volumetric method was used to measure the desorption of methane between 50 psig and atmospheric pressure for seven composite samples from three different seams. Table 5-1 shows the apparent desorption of these samples for methane and carbon dioxide for the pressure difference of 50 psig to 0 psig as measured by this method. (All volumes of sorption in this table and other tables in this thesis have been corrected to standard conditions, namely 0°C and 760 mm Hg). Each value shown in the table is the average of two tests, and the average deviation from the mean value of individual samples was found to be ± 3 cu.ft./ton.

Two size ranges were tested (-100 +200 and -200 +0 mesh) to determine if the -100 +200 mesh fragments were saturated at test conditions as concluded by Singh. The table shows that the values of apparent desorption of methane and carbon dioxide for the -200 +0 mesh sizes are higher than the apparent desorption for the -100 +200 mesh sizes in 6 out of 7 samples. Although the differences between the two size ranges are not great, they indicate that the -100 +200 mesh sizes were not fully saturated at the test conditions.

TABLE 5-1

Apparent Sorption Capacity at 21°C by Volumetric Method

Mine	Seam	Composite Sample No.	Volume Desorbed from 50 psig to 0 psig (cu.ft./ton)			
			Methane		Carbon Dioxide	
			-100 +200	-200 +0	-100 +200	-200 +0
Balmer N	Balmer W	937-939	165	179	259	289
"	"	943-947	156	176	255	289
"	"	948-953	153	156	248	287
Vicary B	-	954-958	127	143	230	257
"	-	959-962	101	111	257	244
Canmore	Wilson	963-967	239	239	336	412
"	"	968-972	229	245	341	365

Note: Volumes corrected to N.T.P. (0°C and 760 mm Hg)

2. Relationship Between Gas Sorption Capacity and Pressure as Measured by the Gravimetric Method

Table 5-2 shows the total sorption capacity for methane expressed on a cu.ft./ton basis for samples from the Balmer West, Vicary B and Wilson seams, through the range of pressures from 0 to 600 psig, as measured by the gravimetric method. The table shows total sorption capacity of the samples on the 'as received' and on the 'dry ash-free' basis. Temperature was kept constant at 21°C (70°F) for these tests and moisture content was between 0.13 - 0.37%. The values shown are the averages of two tests, and the average deviation from the mean value was found to be ± 1.4 cu.ft./ton.

Figure 5-1 shows the methane sorption isotherms of 3 individual samples from the Balmer West, Vicary B and Wilson seams. These curves of total sorption capacity are typical in that they are steepest at low pressures and become flatter at high pressures. In none of the tests was a limiting value for sorption reached at 600 psig pressure, this limit generally being reached around 70-150 atm of pressure according to Palvelev and Taylor.

Figures 5-2 and 5-3 show isotherms for the total sorption of methane for two sets of coal samples that were taken in continuous roof-to-floor sequences from the Wilson and from the Balmer West seams respectively. The isotherms of the Wilson seam section are quite similar to each other, while one of the samples from the Balmer West (Sample No.937) shows appreciably high total sorption capacity in comparison

TABLE 5-2

Total Methane Sorption @21°C - Gravimetric Method

Mine	Seam	Sample No.	Total Sorption Capacity cu.ft./ton																	
			Ash Included Basis								D.a.f. Basis									
			0	50	100	200	300	400	500	600	0	50	100	200	300	400	500	600		
Pressure psig.																				
Balmer N	Balmer W	937	88.68	244.9	333.3	446.6	525.2	593.2	654.3	707.8	117.3	323.8	440.8	590.6	694.7	784.4	865.3	935.4		
"	"	938	94.02	261.9	353.4	464.7	536.1	590.1	640.8	679.7	103.4	288.2	388.9	511.4	589.8	649.9	705.1	747.9		
"	"	939	95.5	267.5	359.9	475.9	542.3	591.2	634.6	668.1	104.3	289.2	388.8	514.6	586.5	639.2	686.1	722.4		
"	"	951	73.1	222.5	329.4	432.2	489.9	539.3	565.8	597.5	80.3	244.5	361.9	474.9	538.3	592.6	621.8	656.6		
Vicary B	-	956	53.8	181.8	273.2	377.6	437.8	483.5	522.1	556.1	55.6	188.0	282.5	390.5	452.7	500.0	539.9	575.1		
"	-	961	32.0	123.0	191.9	271.6	313.4	349.9	380.7	395.9	35.4	136.1	212.3	300.4	346.7	387.1	421.1	437.9		
Canmore	Wilson	963	104.1	301.8	422.1	546.1	629.3	684.2	728.4	774.7	109.9	318.7	445.7	576.7	664.5	722.5	769.2	818.1		
"	"	964	128.2	336.8	462.8	582.3	664.0	729.5	776.7	814.0	137.8	362.1	497.6	526.1	626.1	714.0	835.2	875.3		
"	"	965	111.9	293.5	401.5	508.4	582.9	641.4	688.1	728.9	130.1	341.3	466.9	591.2	677.8	745.8	800.1	847.5		
"	"	966	135.8	326.5	451.7	569.1	651.9	713.9	766.9	807.7	142.8	343.3	474.9	598.4	685.5	750.7	806.4	849.3		
"	"	967	138.5	352.8	479.1	600.2	685.3	752.6	803.6	844.9	142.6	363.3	493.3	618.1	705.8	775.1	827.6	870.1		
"	"	970	98.0	259.8	358.5	475.7	556.9	616.9	674.6	740.2	119.5	316.8	437.2	580.1	679.1	752.3	822.7	902.7		

Note: Coal tested with moisture in 'as stored' condition.

with isotherms for the other coal samples from the same section. This sample, No.937, was taken from a layer of coal next to the roof; by proximate analyses it was found to be much higher in ash content than the other samples of the section, and its ΔP value was also the highest in the section ($\Delta P = 27$). The reasons for the difference in its sorption capacity from those of the neighboring samples are not evident. These sections suggest that in many cases the sorption isotherms for all layers in a given coal seam may be expected to be quite similar.

Some values for total sorption of methane were tested for conformity with the theory of Langmuir by plotting P/V against P (see Figure 5-4). In all cases when values of total sorption capacity for pressures over 200 psig were plotted in this manner a straight line was obtained. This indicates that sorption in the 200-600 psig pressure range appears to conform to the Langmuir equation and is compatible with the hypothesis of Langmuir that methane is adsorbed in a mono-molecular layer on the surfaces of the coal.

3. Comparison of Total Sorption of Carbon Dioxide and Methane

Table 5-3 shows the total sorption capacity for carbon dioxide through the 0 to 600 psig range of pressure for three samples of dry coal from the Balmer West, Vicary B and Wilson seams at 21°C. Figures 5-5, 5-6 and 5-7 show this information plotted as isotherms and also the total sorption isotherms for methane for the same samples. The total

TABLE 5-3

Total Carbon Dioxide Sorption @21°C

Mine	Seam	Sample No.	Total Sorption Capacity cu.ft./ton																	
			Ash Included Basis									D.a.f. Basis								
			0	50	100	200	300	400	500	600	0	50	100	200	300	400	500	600		
Balmer N	Balmer W	951	270.1	566.1	681.0	830.0	924.3	993.7	1033.4	1066.1	295.1	618.7	744.3	907.1	1010.2	1086.0	1129.4	1165.1		
	Vicary B	956	264.3	533.5	652.4	796.4	893.9	972.9	1031.3	1099.4	272.5	550.0	672.6	821.0	921.5	1003.0	1063.2	1133.4		
Canmore	Wilson	964	387.4	762.0	900.0	1065.5	1165.3	1242.7	1303.2	1340.5	415.7	817.6	965.7	1143.2	1250.3	1333.4	1398.3	1438.3		

sorption capacity of coal for carbon dioxide is seen to be always greater than that for methane, especially at low pressures. Table 5-4 shows the ratios of the total amount of sorbed carbon dioxide to methane at different gas pressures.

TABLE 5-4

Ratio of the Total Amount of Sorbed Carbon Dioxide
to Methane at Different Gas Pressures

Gas Pressure psig	Ratio of CO ₂ : CH ₄		
	Balmer W Sample No.951	Vicary B Sample No.956	Wilson Seam Sample No.964
0	2.72 : 1	3.03 : 1	2.87 : 1
50	1.99 : 1	2.04 : 1	1.98 : 1
100	1.86 : 1	1.93 : 1	1.81 : 1
200	1.79 : 1	1.84 : 1	1.73 : 1
300	1.77 : 1	1.81 : 1	1.68 : 1
400	1.74 : 1	1.78 : 1	1.66 : 1
500	1.69 : 1	1.75 : 1	1.63 : 1
600	1.61 : 1	1.70 : 1	1.55 : 1

The ratios are plotted against pressure for these three samples in Figure 5-8. The figure indicates a sharp decrease in the ratio of CO₂ to CH₄ as pressure increases from 0 to 50 psig, and the plots of the ratio for the three different samples are almost parallel for pressures above 100 psig. At atmospheric pressure (0 psig) the ratio of CO₂ to CH₄ was found to be between 2.7 and 3.0, and this ratio decreased with the rise of pressure until at 600 psig (about 42 atmosphere) it was found to be from 1.5 to 1.7. This

indicates that the sorption of carbon dioxide on coals appears to become complete before that of methane. These ratios of CO_2 to CH_4 are in general agreement with the observations of Graham and Gunther, and with the observation of Ettinger et al, who found the value of the ratio of CO_2 to CH_4 at 40 atmospheres to range from 1.5 to 1.7.

Table 5-5 shows the ratio of CO_2 to CH_4 with volatile content for the three samples for which data is available. The number of samples tested is not enough to enable any conclusions to be drawn in regard to the relationship of the CO_2/CH_4 ratio to volatile matter.

TABLE 5-5

Volatile Matter vs CO_2/CH_4 Ratio
(At atmospheric pressure)

Seam	Sample No.	V.M. %	CO_2/CH_4 at 0 psig
Balmer W	951	19.7	2.72
Wilson	964	19.7	2.87
Vicary	956	22.3	3.03

In Figures 5-5, 5-6 and 5-7 the solid-line isotherms represent total sorption which includes both the gas sorbed on the sample surfaces of the coal and that which is compressed within the pore spaces. The dotted lines represent apparent sorption capacity i.e. the amount of gas held on the coal surfaces. The bottom solid line represents

the amount of gas compressed in the pores, as determined by using helium instead of methane, and following the same procedure of determining the volume of gas by the gravimetric method. Thus, in the graphs, the apparent sorption is the difference between the total sorption and the gas in the pores (as determined by using helium).

In these figures it is shown that the amounts of compressed gas in pores is insignificant at low pressures, but increases with increase of pressure until at 600 psig the compressed gas in pores represents about 10-15% of the total sorption capacity. The volume of compressed gas in pore spaces was found to be about 90-100 cu.ft./ton at 600 psig pressure. This agrees with the results of studies carried out by Jolly, Morris and Hinsley who found the volume of compressed gas in pore spaces to be about 100 cu.ft./ton at 720 psig (50 atm) for some English coals. Porosities of the three different samples from the Balmer W, Vicary B and Wilson seams were calculated from the slope of the straight portions of the plots and found to be 7.1%, 7.9%, 9.8% respectively.

Figure 5-9 shows the volume of helium compressed in pore spaces at different pressures in more detail than in Figures 5-5, 5-6 and 5-7. The curved parts of the plots at low pressures can perhaps be attributed to slight impurities in the helium (such as N_2) which were sorbed by the coal, or to some unknown experimental error, or to slight but actual

sorption of helium by the coal. More investigation needs to be done to clarify and explain this behavior of helium at low pressure, especially since several authors have stated or assumed that helium is not sorbed by coal.

4. Effect of Moisture Content on Total Sorption Capacity

Table 5-6 shows the total sorption capacity of three samples, from Balmer West, Vicary B and the Wilson seam, at four different moisture contents for a range of pressures from 0 to 600 psig, and Figures 5-10, 5-11 and 5-12 show the resulting sorption isotherms. These isotherms indicate the decrease in total sorption capacity with increase of moisture content.

Figure 5-13 shows total sorption capacity of these coals with various moisture contents as a percentage of the sorption capacity of dry coal against the percentage of moisture content at 0 and at 600 psig (at 21°C). The plot indicates that reduction of sorption capacity due to moisture content is greater at lower pressures than at higher pressures. The effect of moisture content at 600 psig on the total sorption is quite similar for the three different samples, while at 0 psig the effect of moisture content is more variable from one sample to another.

The decrease in the effect of moisture content on the sorption capacity at high pressure is probably due to the fact that water is more easily sorbed by coal than methane or carbon dioxide. At low pressures the proportion of sorbed

TABLE 5-6

Effect of Moisture on Total Methane Sorption
(At 21°C, Different Moisture Contents)

Mine	Seam	Sample No.	Moisture Content %	Total Sorption Capacity cu.ft./ton																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
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methane is much greater than the amount of compressed methane in pore spaces, and this is the methane which can be displaced by moisture,-- therefore the influence of moisture content is high. At high pressures a larger proportion of methane is contained by coal in a free state (as compressed gas in pore spaces), in which case the influence of the moisture sorbed by coal is probably not as great.

Experimental results were compared with the total sorption capacity to be expected at different moisture contents from Ettinger's empirical formula, namely -

$$\frac{\text{Total sorption capacity of humid coal}}{\text{Total sorption capacity of dry coal}} = \frac{1}{1 + 0.31H}$$

where H is the moisture content in percentage. Table 5-7 shows the experimental results (d.a.f. basis) and the values calculated from Ettinger's formula for total sorption capacity for the range of pressure 0 to 600 psig. Figure 5-13 shows that Ettinger's formula does fit experimental data at atmospheric pressure within a reasonable limit for moisture contents from about 0.7% to about 2.5% but for conditions beyond 50 psig Ettinger's formula is of limited validity.

Figure 5-13 indicates that there is up to a 25% difference in sorption for a change from 0 to 0.3% moisture content. This suggests that the control or recognition of small amounts of moisture is very important when measuring sorption of gas in the laboratory or the desorption of gas in situ.

TABLE 5-7

Effect of Moisture on Total Methane Sorption
(Experimental and Calculated from Ettinger's Equation)

Mine	Seam	Sample No.	Moisture Content %	Total Sorption Capacity cu.ft./ton																		
				Experimental, D.a.f. Basis											Ettinger's Formula							
				Pressure psig.											0	50	100	200	300	400	500	600
Balmer N	Balmer W	951	Dry 0.31 0.64 3.44	108.3	310.9	399.9	507.4	571.0	624.4	667.1	722.9											
				73.1	222.5	329.4	432.2	489.9	539.3	565.8	597.5											
				71.8	234.3	303.6	399.2	466.0	513.1	552.8	574.7											
				54.0	192.4	265.0	355.6	415.2	465.5	497.4	517.8											
Vicary B	-	956	Dry 0.33 0.98 2.40	89.9	268.9	347.7	447.0	509.8	564.7	608.1	667.7											
				-	-	273.2	377.6	437.8	483.5	522.1	556.1											
				58.5	203.1	264.1	354.1	422.0	461.7	510.0	540.2											
				43.0	165.5	228.0	315.4	376.1	432.7	459.8	495.4											
Canmore	Wilson	964	Dry 0.13 1.09 3.34	144.6	413.5	533.8	660.3	745.3	803.2	859.6	927.4											
				128.2	336.8	462.8	582.3	664.0	729.5	776.7	814.0											
				89.7	297.4	384.6	510.6	601.6	658.6	707.2	746.0											
				66.5	246.5	337.9	463.4	533.7	603.9	643.4	681.1											

5. Effect of Temperature on Total Sorption Capacity at Different Pressures

Tables 5-8, 5-2, 5-9 and 5-10 show total sorption capacity for methane of samples from the Balmer West, Vicary B and Wilson seams at 4.4; 21, 38 and 54°C respectively for the range of pressures 0 to 600 psig, and Figures 5-14, 5-15, 5-16 and 5-17 show these values plotted as isotherms. These isotherms show that sorption capacity decreases significantly with an increase of temperature. This is in accordance with the theory of physical adsorption which indicates that adsorption of gas by a solid is accompanied by evolution of heat which is called the heat of adsorption (Maron and Prutton). The amount of sorbed gas decreases as the temperature is raised, since this changes the equilibrium between condensation and evaporation of molecules by increasing the rate of evaporation. An increase of 1°C was found to decrease the total sorption capacity by about 1.7%, 1.9% and 2.0% for Samples 951, 956 and 963 from the Balmer West, Vicary B and Wilson seams respectively at atmospheric pressure and 21°C. Gunther reported that for some French coals the decrease in total sorption capacity was about 0.8% for an increase in temperature by 1°C. For one sample of an English coal Jolly, Morris and Hinsley found this decrease was about 2%, and the data given by Daines for one sample showed a decrease of about 1.5% per degree of increase.

TABLE 5-8

Effect of Temperature on Total Methane Sorption
(At 4.4°C, Natural Moisture Content)

Mine	Seam	Sample No.	Total Sorption Capacity cu.ft./ton																	
			Ash Included Basis									D.a.f. Basis								
Pressure psig.			0	50	100	200	300	400	500	600	0	50	100	200	300	400	500	600		
Balmer N	Balmer W	951	116.3	310.8	425.6	541.9	607.1	651.5	700.7	-	127.8	341.5	467.7	595.5	667.1	715.9	770.0	-		
Vicary B	-	956	94.2	260.9	379.8	490.1	573.6	601.7	669.1	-	97.4	269.8	392.8	506.8	593.1	622.2	691.9	-		
"	-	961	63.7	182.3	280.8	365.4	420.0	490.8	502.2	-	70.5	201.6	310.6	404.3	464.6	542.9	555.5	-		
Canmore	Wilson	963	156.0	409.4	530.2	694.9	773.6	826.8	878.1	913.2	164.7	432.3	559.8	733.8	816.9	873.1	927.2	964.3		
"	"	970	125.6	317.4	425.2	579.4	659.6	729.9	792.5	843.0	153.2	387.1	518.5	706.6	804.3	890.1	966.5	1028.0		

TABLE 5-9

Effect of Temperature on Total Methane Sorption
(At 38°C, Natural Moisture Content)

Mine	Seam	Sample No.	Total Sorption Capacity cu.ft./ton																	
			Ash Included Basis									D.a.f. Basis								
Pressure psig.			0	50	100	200	300	400	500	600	0	50	100	200	300	400	500	600		
Balmer N	Balmer W	937	30.0	147.9	224.1	330.7	411.0	476.6	533.5	559.7		39.9	195.6	296.3	437.2	543.1	630.4	705.6	740.1	
"	"	938	22.7	150.1	234.1	330.1	403.4	458.3	504.7	526.3		29.4	165.1	257.6	363.2	443.9	504.3	554.7	579.7	
"	"	939	32.1	164.1	245.4	342.3	405.4	462.4	504.4	517.5		34.8	177.4	265.4	370.2	438.3	500.4	545.3	559.0	
"	"	951	47.4	167.8	254.1	352.0	414.7	459.8	506.3	517.4		52.1	184.4	279.2	386.8	455.7	505.3	556.4	568.6	
Vicary B	-	956	28.1	141.1	208.8	300.0	359.9	411.6	462.4	483.4		29.1	145.9	215.9	310.2	372.2	425.6	478.2	499.9	
"	-	961	15.0	99.0	148.6	217.7	259.3	290.1	327.7	331.5		16.6	109.5	164.4	240.8	286.8	320.9	362.5	366.7	

TABLE 5-10

Effect of Temperature on Total Methane Sorption
(At 54°C, Natural Moisture Content)

Mine	Seam	Sample No.	Total Sorption Capacity cu.ft./ton																	
			Ash Included Basis									D.a.f. Basis								
			0	50	100	200	300	400	500	600	0	50	100	200	300	400	500	600		
Pressure psig.																				
Balmer N	Balmer W	937	30.1	133.0	211.7	317.8	367.7	424.4	-	-		39.7	175.9	279.9	420.2	486.3	561.3	-	-	
"	"	938	23.7	125.1	200.1	297.6	356.1	397.0	-	-		25.9	137.7	220.1	327.0	391.8	436.8	-	-	
"	"	939	26.0	125.7	201.0	304.2	359.4	400.4	-	-		28.1	135.0	218.5	328.8	388.5	432.9	-	-	
"	"	951	18.8	134.9	213.7	300.8	343.1	382.5	433.1	451.5		20.7	148.2	234.8	330.5	377.0	420.3	-	496.1	
Vicary B	-	956	6.41	108.2	173.1	250.3	310.8	332.5	373.8	411.6		6.6	111.9	179.0	258.8	321.4	343.8	386.5	425.6	
"	-	961	-	62.7	109.4	171.7	212.7	229.5	260.5	275.3		-	69.3	121.0	189.9	235.3	253.9	288.2	304.5	

Figures 5-18 and 5-19 show a plot of total sorption against temperature for pressures from 0 to 600 psig; Figures 5-20 and 5-21 indicate that the percentage decrease in total sorption, resulting from an increase in temperature, is higher at low pressures than at high pressures. For adsorption in general it has been stated by Adamson that at low temperatures chemisorption may be so weak that for practical purposes only physical adsorption is observed, whereas at high temperatures physical adsorption is small (because of the low adsorption energy), and only chemisorption occurs. The graphs of percentage of sorption against temperature at low pressure suggest, because of the strong effect of temperature on the percentage change of sorption, that physical adsorption is predominant. At high pressures, the graphs suggest two possibilities, either that the effect of temperature at high pressures on physical adsorption is less (on a percentage basis) than at low pressures, or else that chemisorption becomes appreciable at high pressures. As another possible explanation of this effect, it may be supposed that at high pressures the inner surfaces are nearly covered by a sorbed mono-layer of gas, held there by the pressure of the free gas in the pores. An increase in temperature might have less effect on the release of the attached molecules when they are held there by high pressure than when the gas pressure in the pores is low.

6. Variation in Total Sorption Capacity with Coal Rank

Figure 5-22 shows total sorption capacity plotted against fixed carbon (which is a measure of coal rank) at 0 and 600 psig. The graph suggests that the higher the coal rank the higher the total sorption capacity within the range studied (74 to 89% fixed carbon). The scatter of the points indicates that not only the rank but also other conditions influence the total sorption capacity of the coal. The increase in total sorption capacity for higher ranks of coal could be attributed to an increase in micro-structures and internal surface area of coal. However the writer's results do not show the 'U'-shaped pattern that was observed by Botham and reported in the paper by Patching and Botham, and the number of samples tested are not enough to enable a firm conclusion to be drawn about the relationship between sorption capacity and coal rank.

7. Relation of Sorption Capacity to ΔP Index

Table 5-11 shows the ΔP index and the total sorption capacity (repeated from Table 5-2) at 0 psig for certain samples from the Balmer West, Wilson and Vicary B seams.

TABLE 5-11

 ΔP_{0-60} Index and Total Sorption Capacity (at 0 psig)

Seam	Sample No.	ΔP_{0-60}	Total Methane Sorption at 0 psig.
Balmer W	937	27	88.7
"	938	16	94.0
"	939	17	95.5
Wilson	963	25	104.1
"	964	13	128.2
"	965	9	111.9
"	966	22	135.8
"	967	21.5	138.5
Vicary B	956	17.5	53.8
"	961	9	32.0

Figure 5-23 shows these sorption and ΔP values for the Balmer and Wilson seams plotted against the positions of the samples in the seams. From these diagrams there appears to be a slight correlation between the ΔP index values and total sorption capacity except for the upper sections. It is noticed from the diagram that the ΔP values of the upper layers of the sections are considerably higher than for the other parts of the sections. In spite of a slight indication that the ΔP index increases with an increase in total sorption capacity, it is recognized that not enough vertical sections are represented in the test results to enable one to infer a definite relationship.

Variations in ΔP values even between samples from one vertical section are possibly due to variations in fissuration, which are directly related to tectonic deformations. Seams of different mines, and even different locations or layers in the same seam, are not subjected to the same magnitudes of tectonic deformation or fracturing. The upper layer of a seam, according to visual inspection (Alpern, Singh), is often more highly sheared than the other layers of the seam, perhaps because tectonic movements tend to occur in coal near its boundaries with the strong roof rocks.

8. Comparison Between Gravimetric and Volumetric Sorption Methods

In the volumetric method, the gas sorbed at atmospheric pressure is not released and consequently is not reported. To obtain a comparison of the volumetric and gravimetric methods, values of total sorption from gravimetric determinations at 0 psig were subtracted from the values from gravimetric determinations at 50 psig for several samples and were compared with the values of apparent sorption obtained by the volumetric method over the same pressure differences for the same samples. For these comparative tests the samples were pulverized to -200 mesh size.

TABLE 5-12

Comparison of Gravimetric and Volumetric Sorption Methods
(Between 50 and 0 psig)

Mine	Composite Sample No.	By Weight Method	By Volumetric Method
Balmer N	942-947	163.4, 162.7	174, 177
"	948-953	152.1, 151.0	157, 155
Vicary B	954-958	135.3	145, 140
"	959-962	118.4	111, 111

Table 5-12 shows the comparison of values of sorption as measured by the two methods. It can be seen that the agreement is quite good, although the volumetric method results are slightly higher than those of the gravimetric method. The differences may be because the samples tested by the gravimetric method were not fully saturated; in the gravimetric tests gas was applied to the samples for about six hours, which appeared to establish constant weight, while for the volumetric tests gas had been applied for about 18 hours. Perhaps also there were slight differences in the coal samples or experimental errors or slight changes in barometric pressure and temperature. It should be noted that the gravimetric method involves sorption of methane and the volumetric method desorption, and so the two processes, sorption and desorption, appear to be reversable and of the same magnitude as already mentioned by other authors.

The gravimetric method of measuring total sorption capacity has the following advantages over the volumetric method:

- a) Total sorption of gas at atmospheric pressure can be measured.
- b) It is more precise and the results are more consistent.

The average deviation from the mean value was found to be ± 1.4 cu.ft./ton for the gravimetric method and ± 3 cu.ft./ton for the volumetric method. A larger error can be expected with the volumetric method due to slight variations within the coal samples because it uses only 6.5 grams of coal while the gravimetric method uses a larger sample of about 40 grams.

- c) It is easier to control temperatures and moisture contents when carrying out the tests.
- d) Increases in weight of gas can be directly converted into volumes at N.T.P., whereas each gas volume measured by the volumetric method requires separate correction for the temperature and pressure at which the gas is measured.
- e) Six samples can be tested simultaneously in the apparatus that has been constructed, whereas each volumetric test assembly requires more space.

The principal disadvantage of the gravimetric method is that it includes the gas compressed in pores of coal, i.e. it only measures the total sorption capacity. However by using helium the volume of pore space can be evaluated and then the apparent sorption can be calculated.

Table 5-13 shows comparisons of sorption capacity as measured by using the standard equivalent volumes (total sorption capacity) and by using helium (apparent sorption capacity) for a set of samples. The differences in results may be due to the error in weighing cells when containing helium, since the proportional errors in weighing helium are higher due to its light weight, especially at low pressures.

TABLE 5-13

Sorption by the Gravimetric Method at 50 psig as Measured by Using Standard Equivalent Volume and by Using Helium

Mine	Sample No.	Sorption Capacity by Using St.Eq.Vol.	Sorption Capacity by Using He
Balmer	943-947	256.3, 259.7	257.9, 257.1
"	948-953	238.4, 235.2	239.6, 239.3
Vicary	954-958	205.9	210.9
"	959-962	176.8	182.6
Balmer	951	284.5	272.5
Vicary	956	260.8	240.8
Canmore	964	385.4	365.4

The important information about sorption capacity from a practical point of view is the capacity of coal for retaining or releasing gas, irrespective of whether it is compressed in pores or sorbed by coal. This means that the values of total sorption as determined by the gravimetric method can be directly applied for practical purposes. If it is required to know the values of apparent sorption at high pressures (over 100 psig), it is possible to use helium instead of a standard equivalent volume.

CONCLUSIONS AND RECOMMENDATIONS

1. There is a general correlation between ΔP_{0-10} and ΔP_{0-60} indices, with considerable scatter in values.
2. Wilson seam samples showed higher values of ΔP_{0-60} index than those from Balmer West, which were higher than those from Vicary B. Sample 986, whose ΔP_{0-60} index was the highest in the writer's set of tests, had been taken from a face in the Wilson seam where a minor outburst had occurred.
3. Variations in coal structure obscure the relationship that may exist between the ΔP index and coal rank.
4. If a given coal is crushed more and more finely, the ΔP index at first reacts slightly to the size of particles and then abruptly begins to increase, presumably when the size of particles becomes smaller than average fissuration size. This is an indication that the ΔP index is linked to coal fissuration.
5. The difference in apparent sorption capacity of two size ranges (-100 +200 and -200 +0 mesh) which were tested by a volumetric method indicates that -100 +200 mesh particles were not fully saturated at test conditions.
6. Sorption isotherms as measured by a gravimetric method are typical in that they are steepest at low pressures and become flatter at high pressures. In none of the

tests was a limiting value for sorption reached at 600 psig pressure.

7. Isotherms of total sorption capacity of methane for a roof-to-floor sequence of samples from the Wilson seam are similar in shape and value.
8. Data from measurements of total sorption of methane for samples from three different seams appears to conform to the Langmuir equation of adsorption for pressures over 200 psig.
9. The ratio of total sorption capacity of CO_2 to CH_4 at atmospheric pressure was found to be between 2.7 and 3.0; this ratio decreased with the rise of pressure until at 600 psig (about 42 atm.) it was found to be from 1.5 to 1.7. This indicates that the sorption of CO_2 on coals appears to approach completion before that of CH_4 .
10. The amount of compressed gas in pores of coal is insignificant at low pressures, but increases with increase of pressure until at 600 psig the compressed gas in pores represents about 10-15% of the total sorption capacity.
11. Plots of the volume of helium in pore spaces are curved at low pressures, and more investigation is needed to clarify and explain the effect.
12. Percentage reduction in sorption capacity due to the increase in moisture content is greater at lower pressures than at higher pressures. The effect of

moisture content at 600 psig on the total sorption of gas is quite similar for all samples of coal, while at 0 psig this effect is more variable from one sample to another.

13. Ettinger's empirical formula for estimating total sorption capacity of humid coal for methane provides a reasonable fit to experimental data at atmospheric pressure for moisture contents in the range from about 0.7% to about 2.5%. For pressures above 50 psig it is of limited validity.
14. A reduction of up to a 25% in sorption capacity was found to result from a change from 0 to 0.3% moisture content. This suggests that the control or recognition of small amounts of moisture is very important when measuring sorption of gas in the laboratory or the desorption of gas in situ.
15. An increase of 1°C (at 21°C and atmospheric pressure) was found to decrease the total sorption capacity by about 1.7%, 1.9% and 2.0% for samples from the Balmer West, Vicary B and Wilson seams; the percentage decrease in total sorption resulting from an increase in temperature is higher at low pressures than that at higher pressures.
16. Total sorption capacity was found to be higher for higher ranks of coal (within the range studied, 74 to 89% fixed carbon).

17. The agreement between the results of the volumetric and gravimetric methods for measuring sorption capacity of coal was quite good, although volumetric method results were slightly higher than those of the gravimetric method. The gravimetric method has several advantages over the volumetric method.

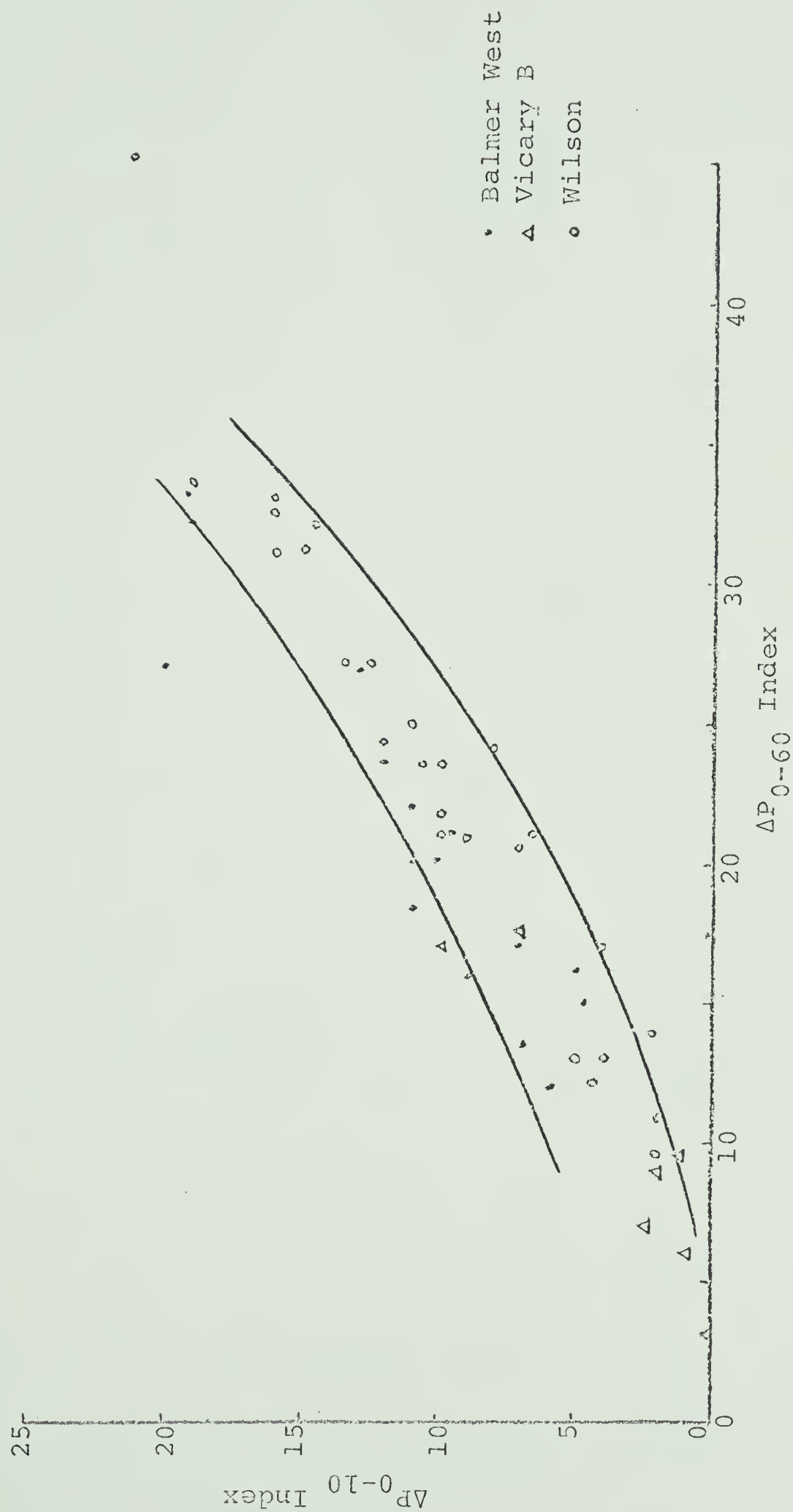


Figure 4-1. Correlation Between ΔP_{0-10} and ΔP_{0-60} Indices

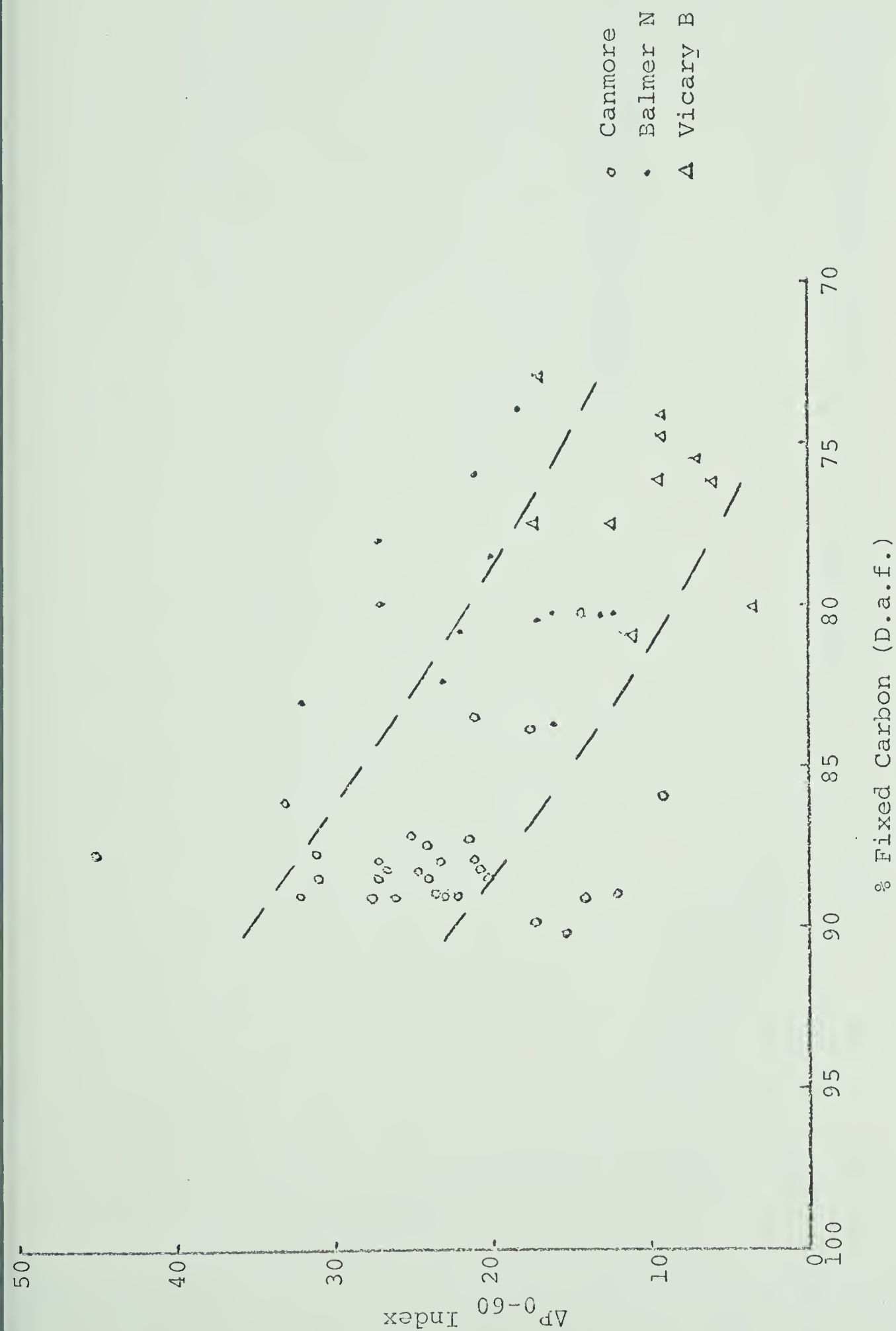
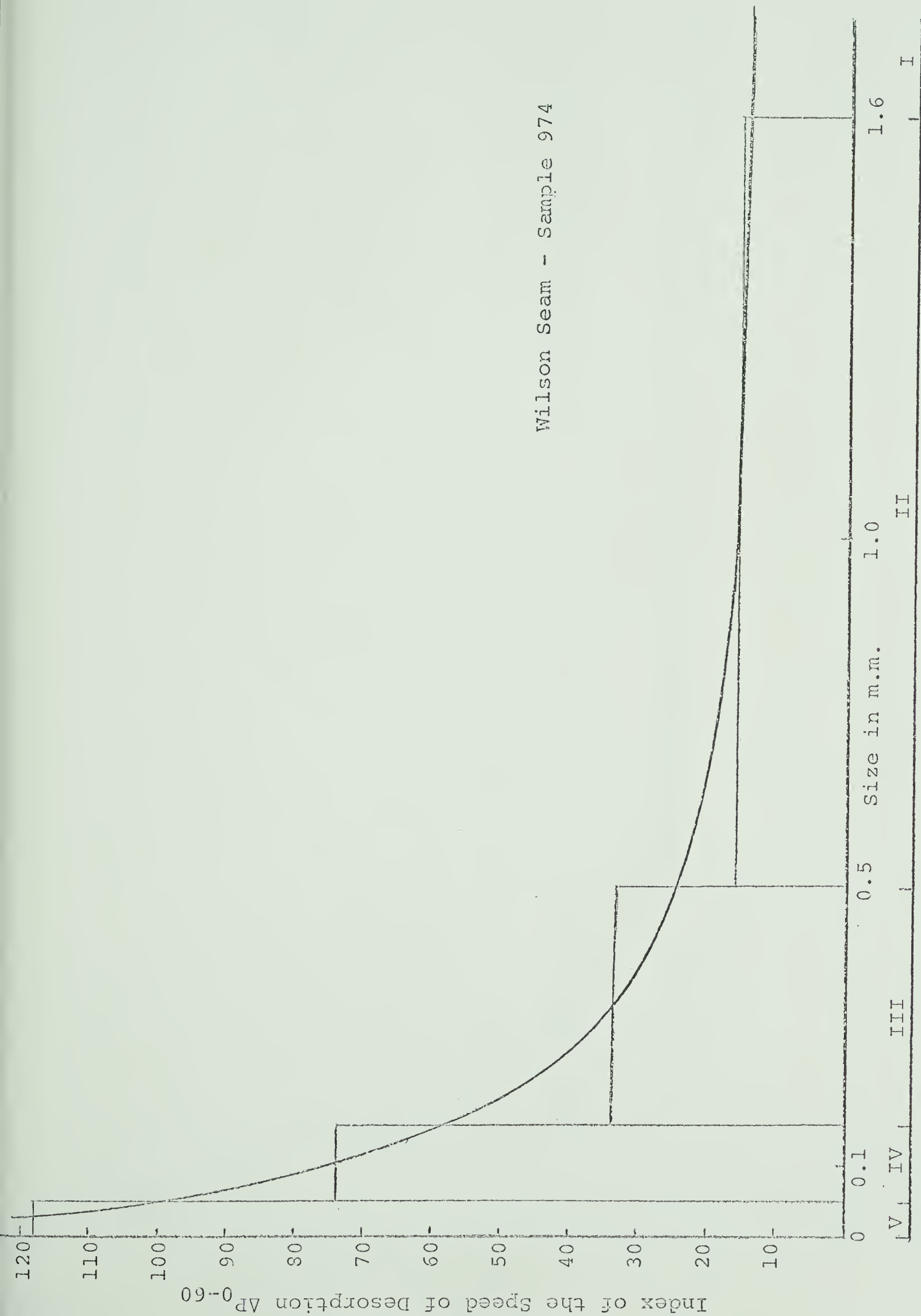


Figure 4-2. Variation of the ΔP_{0-60} Index with Rank

Wilson Seam - Sample 974

Figure 4-3. Variation in the Index ΔP in Function of Size

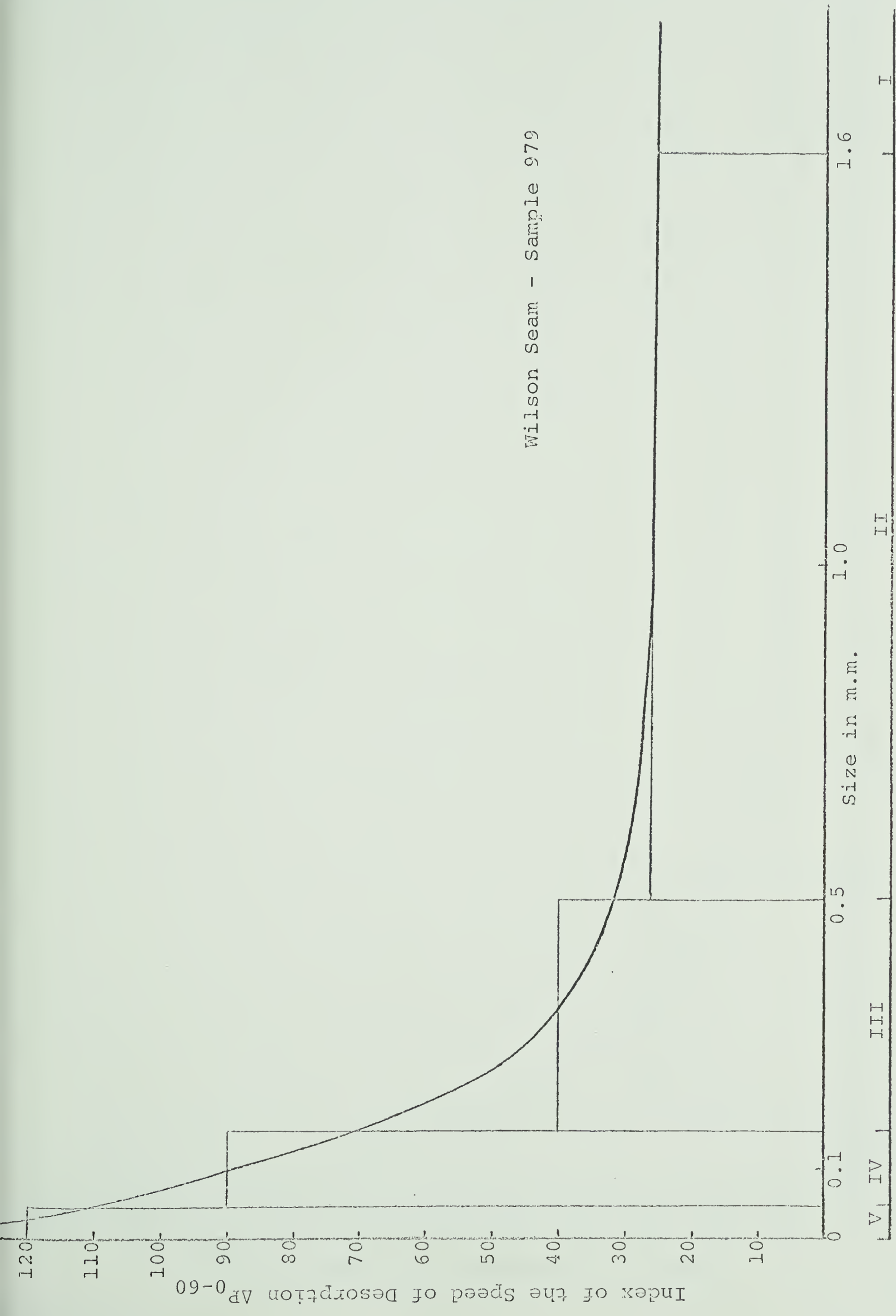


Figure 4-4. Variation in the Index ΔP in Function of Size

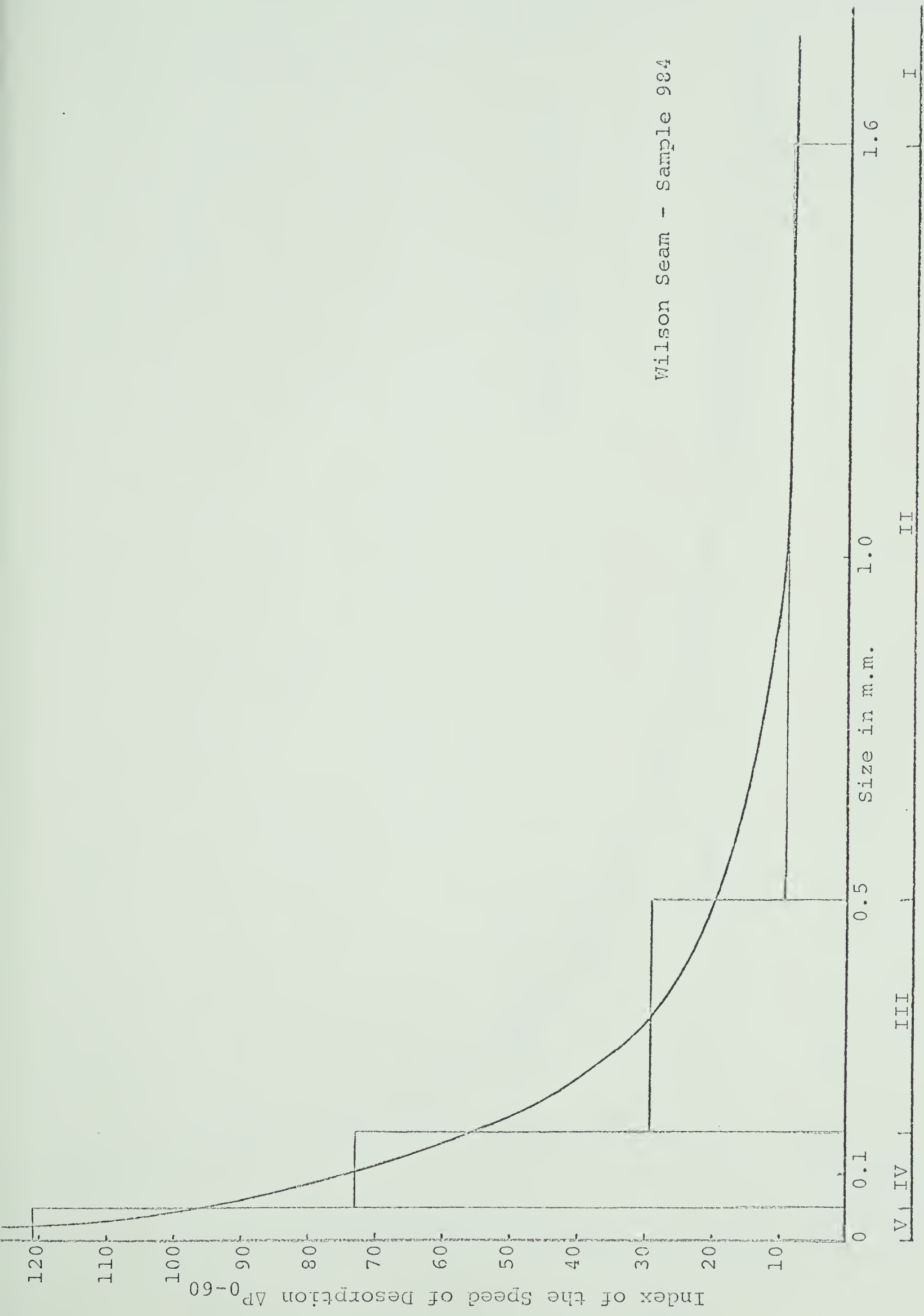


Figure 4-5. Variation in the Index ΔP in Function of Size

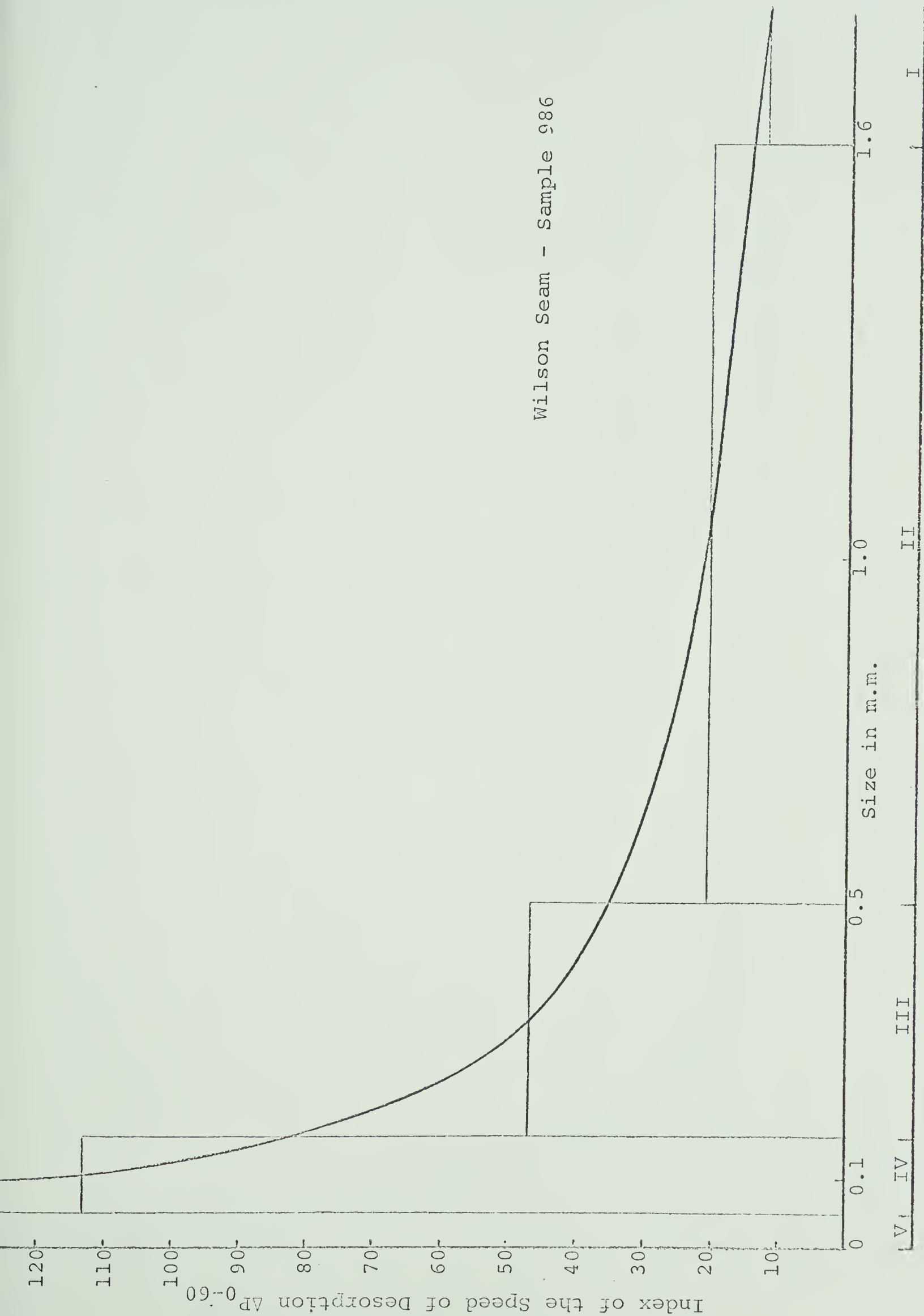


Figure 4-6. Variation in the Index ΔP in Function of Size

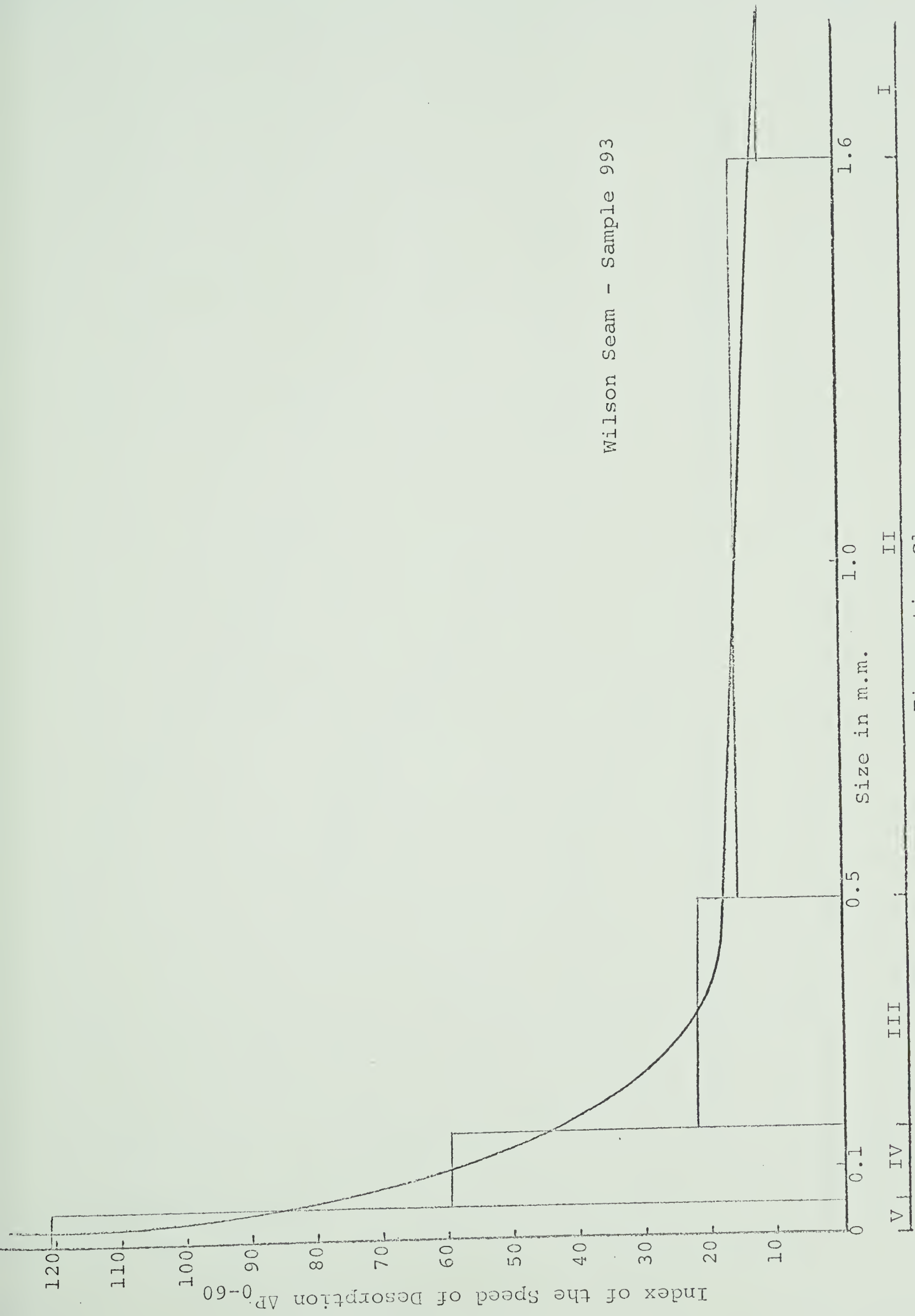


Figure 4-7. Variation in the Index ΔP in Function of Size

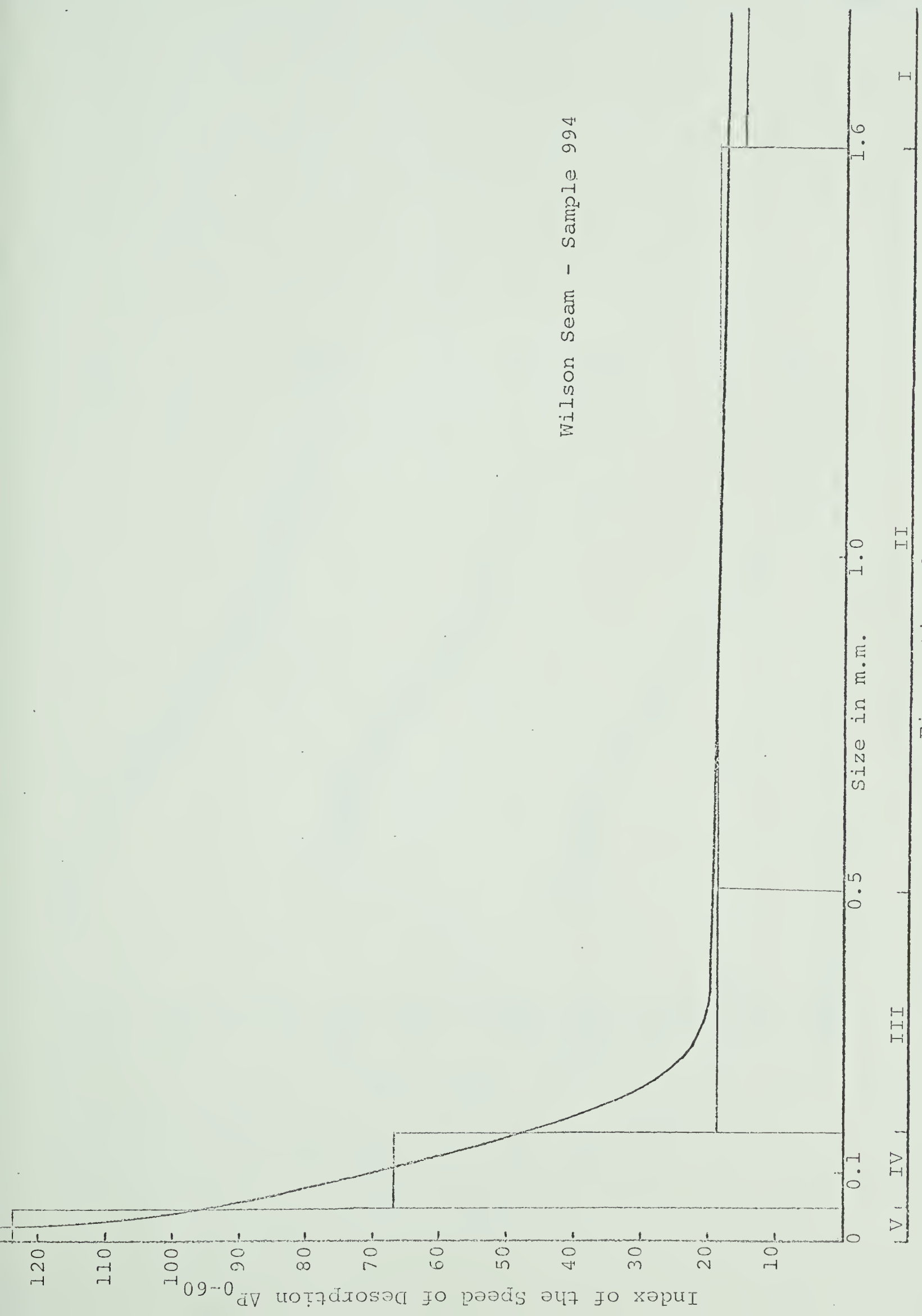


Figure 4-8. Variation in the Index AP in Function of Size

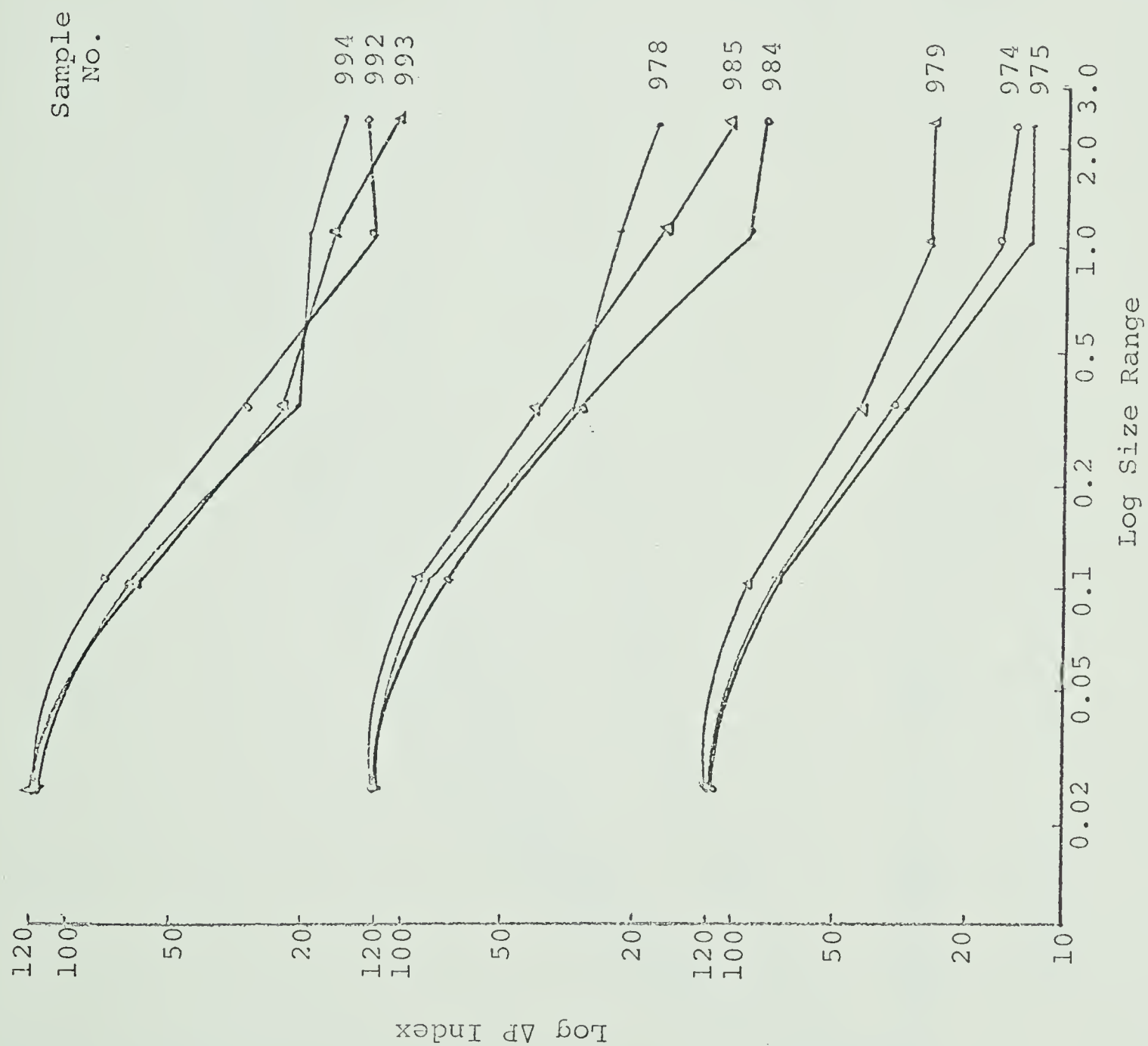


Figure 4-9. Plot of Log ΔP Values Against Log Size

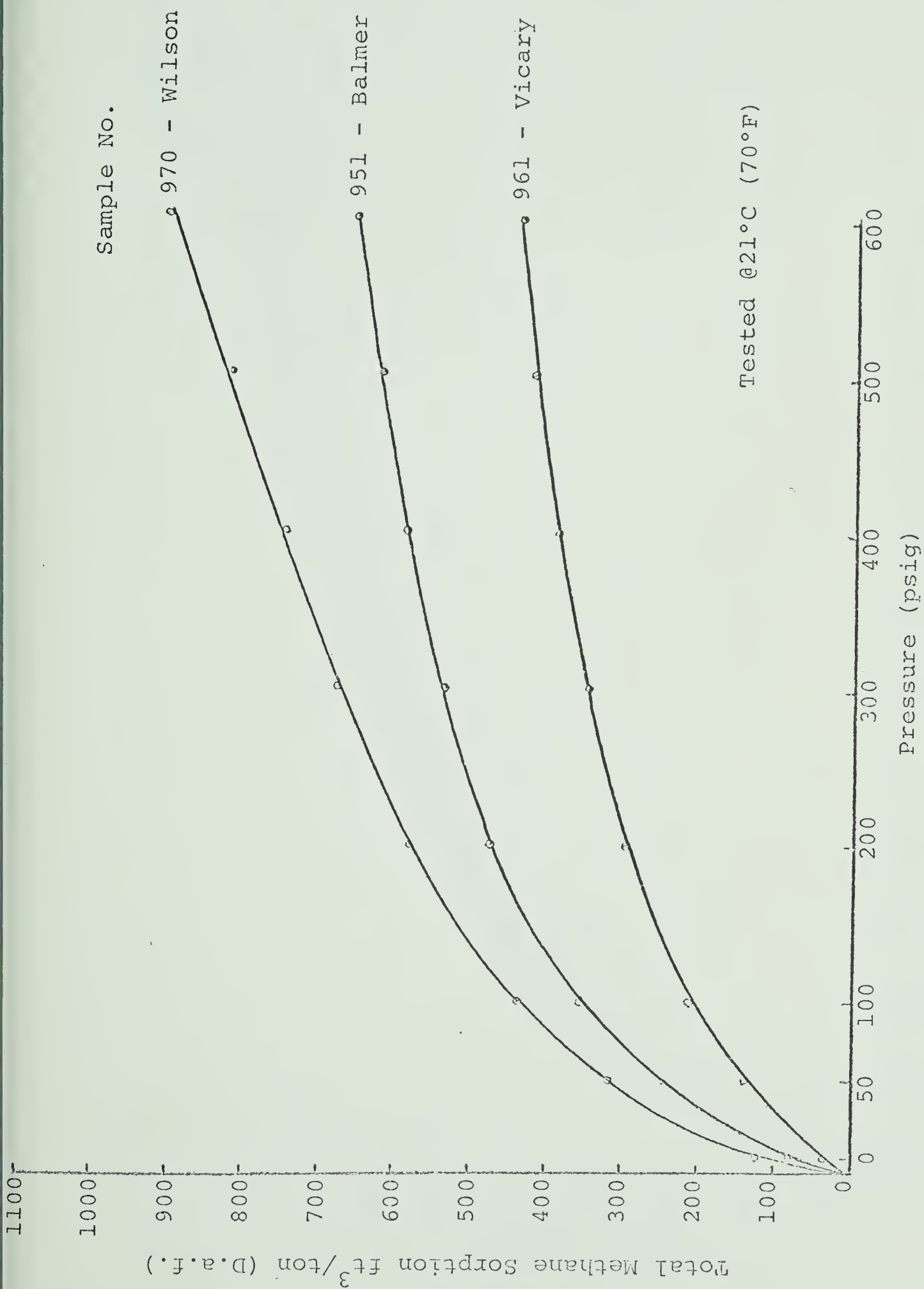


Figure 5-1. Typical Total Sorption Isotherms

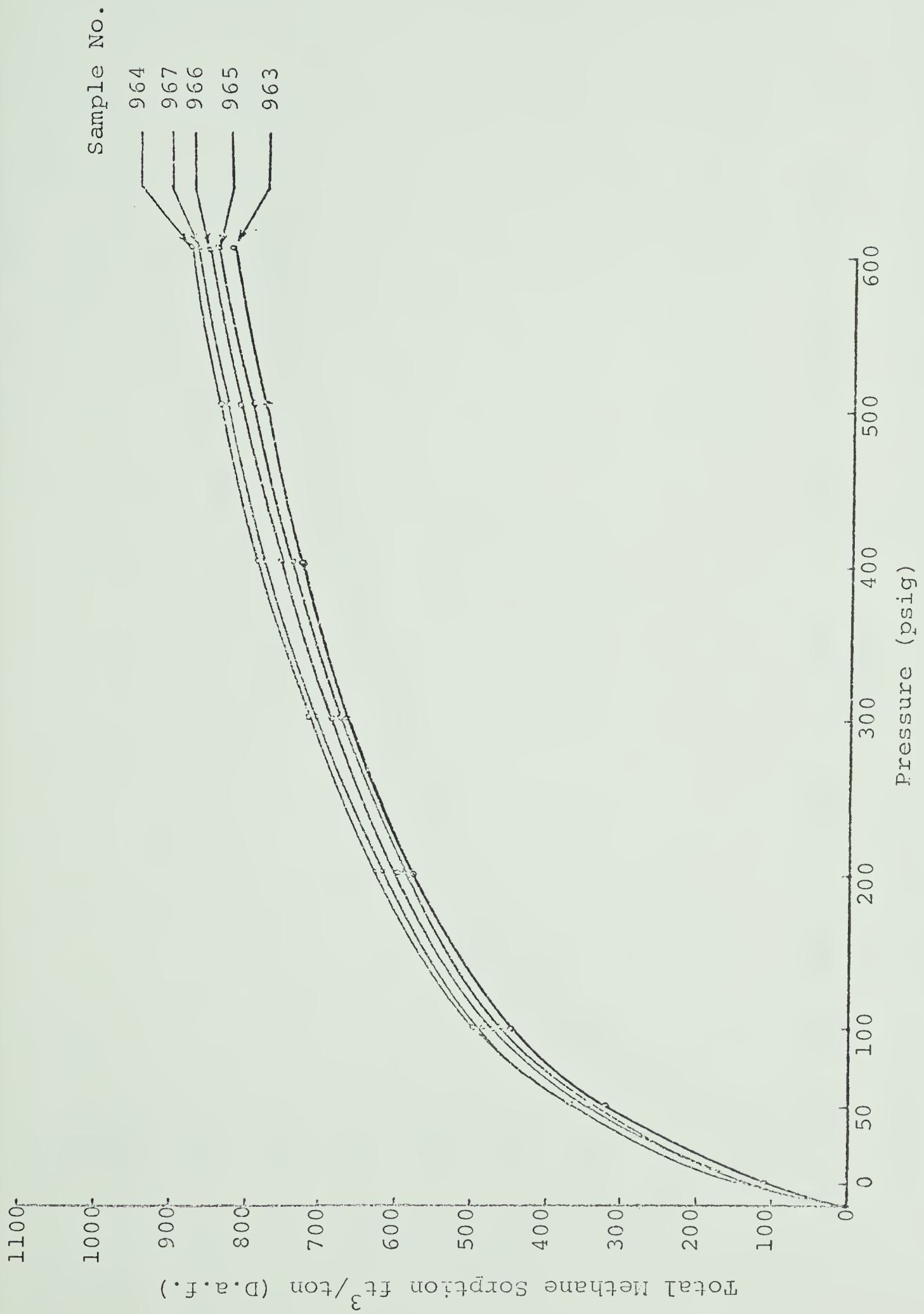


Figure 5-2. Sorption Isotherms - Wilson Seam - Roof to Floor Section

Sample No.

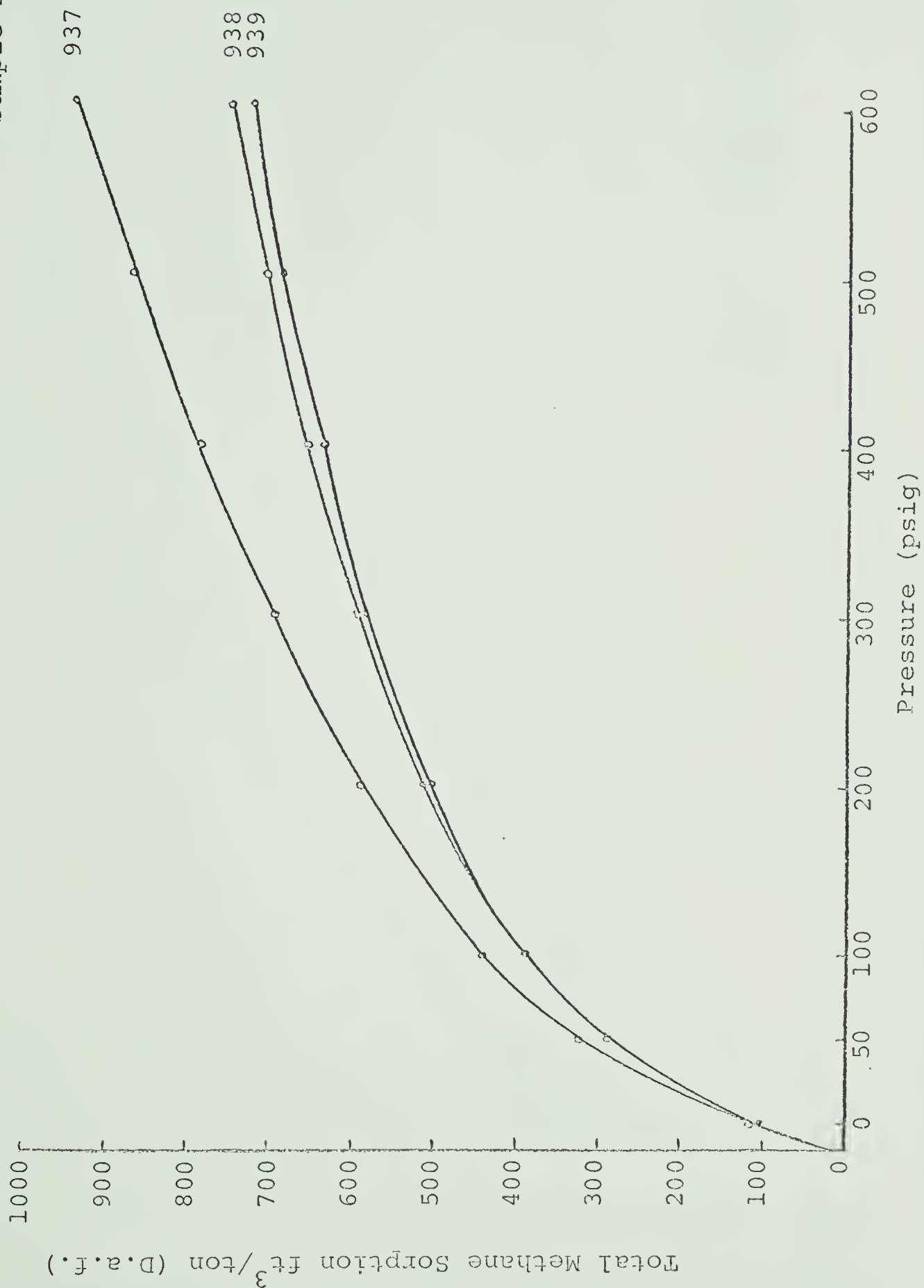


Figure 5-3. Sorption Isotherms - Balmer West - Section below Roof

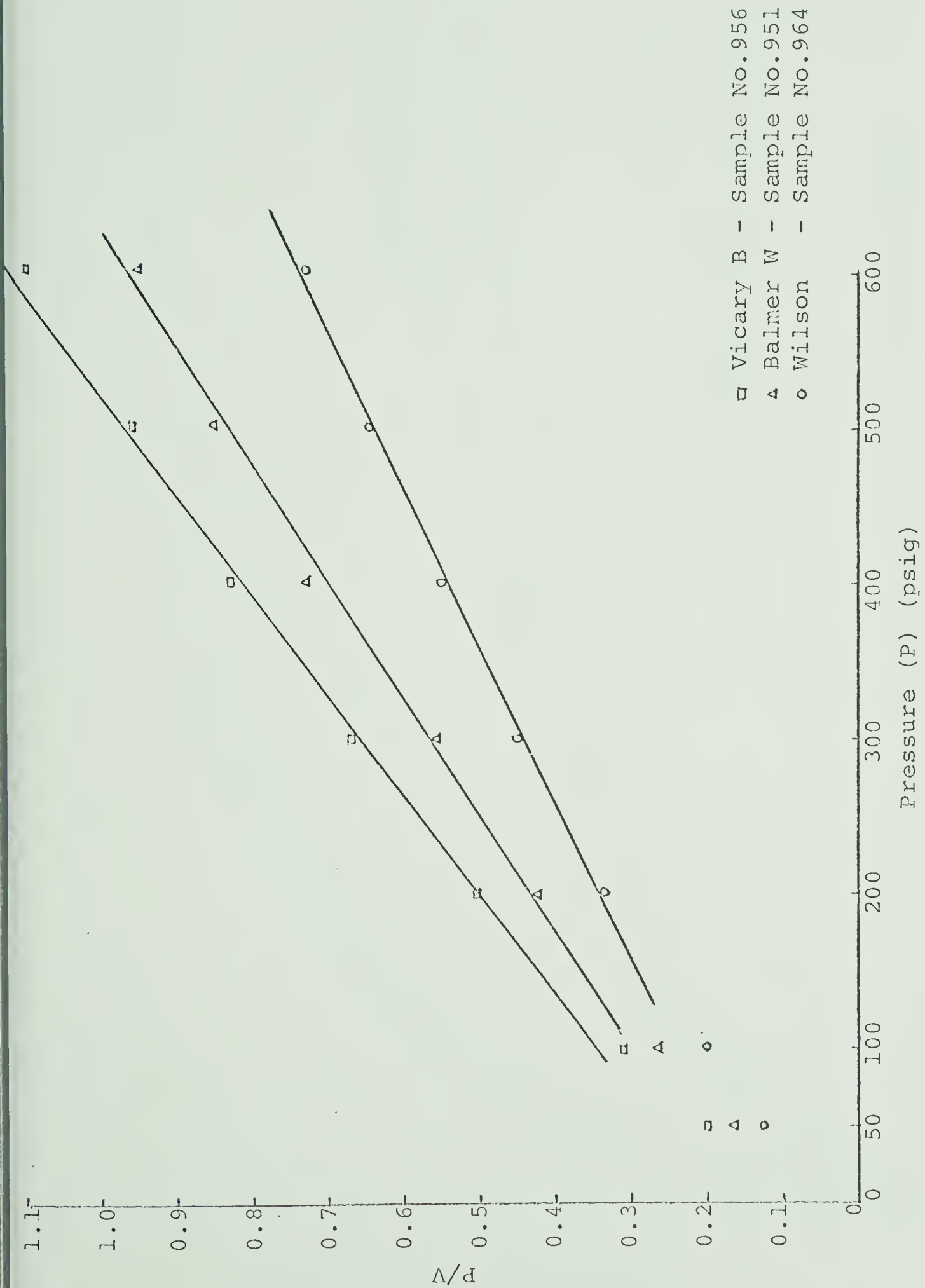
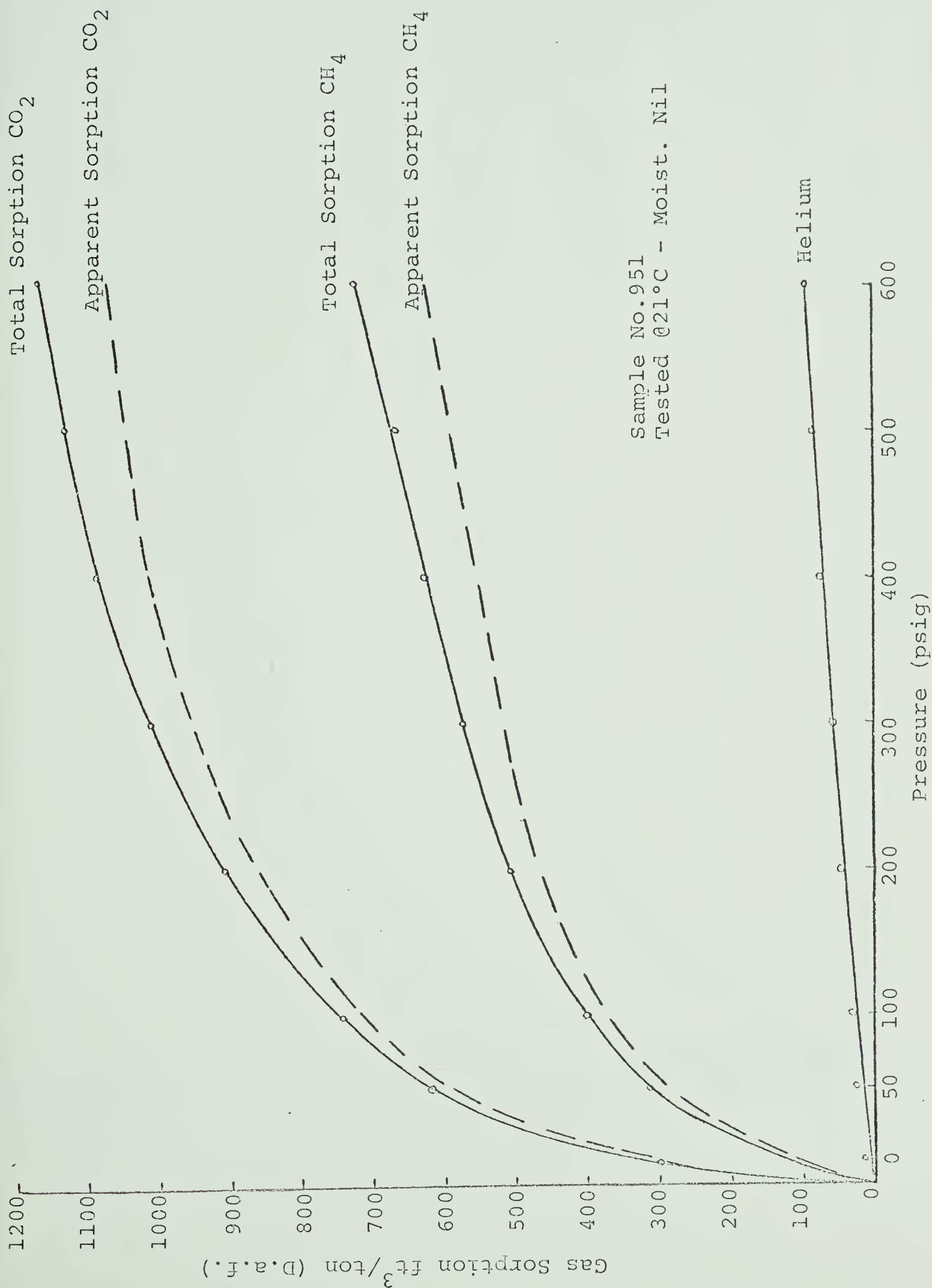


Figure 5-4. Application of Langmuir Equation to Sorption of Methane in Coal

Figure 5-5. Total vs Apparent Sorption of CO₂ & CH₄ - Balmer W Seam

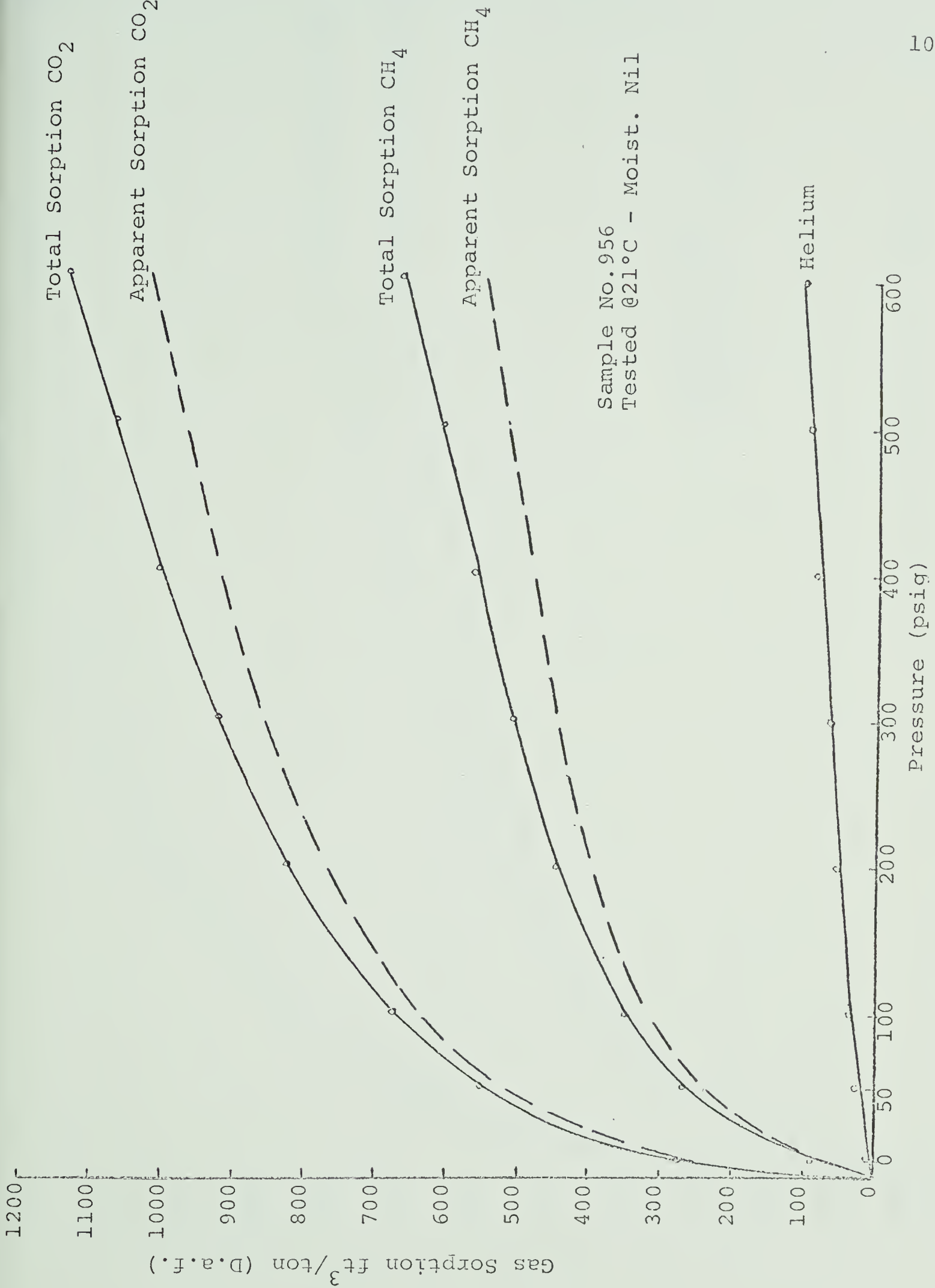


Figure 5-6. Total vs Apparent Sorption of CO_2 & CH_4 - Vicary Seam.

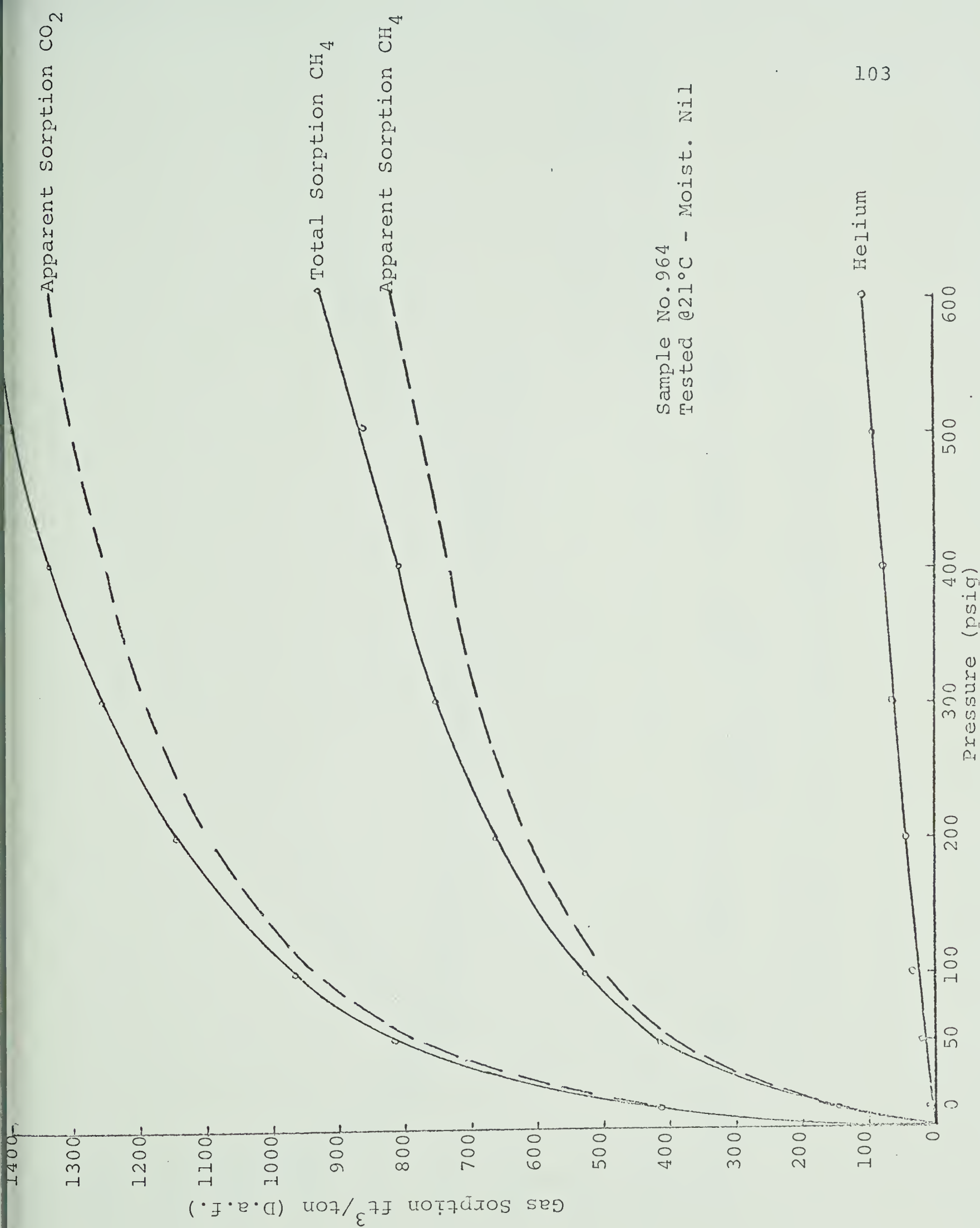


Figure 5-7. Total vs Apparent Sorption of CO_2 & CH_4 - Wilson Seam

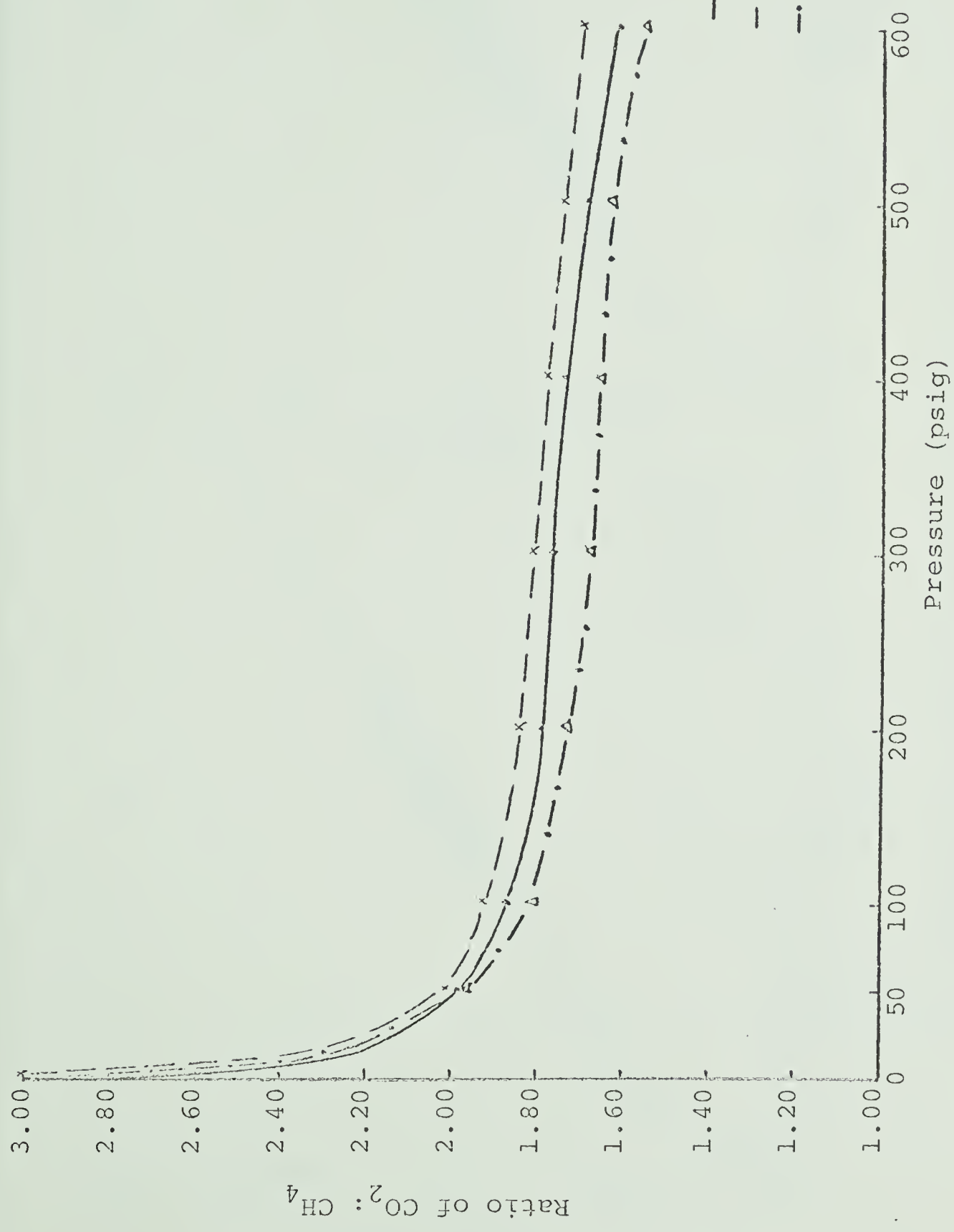


Figure 5-8. Ratio of CO₂/CH₄ Against Pressure

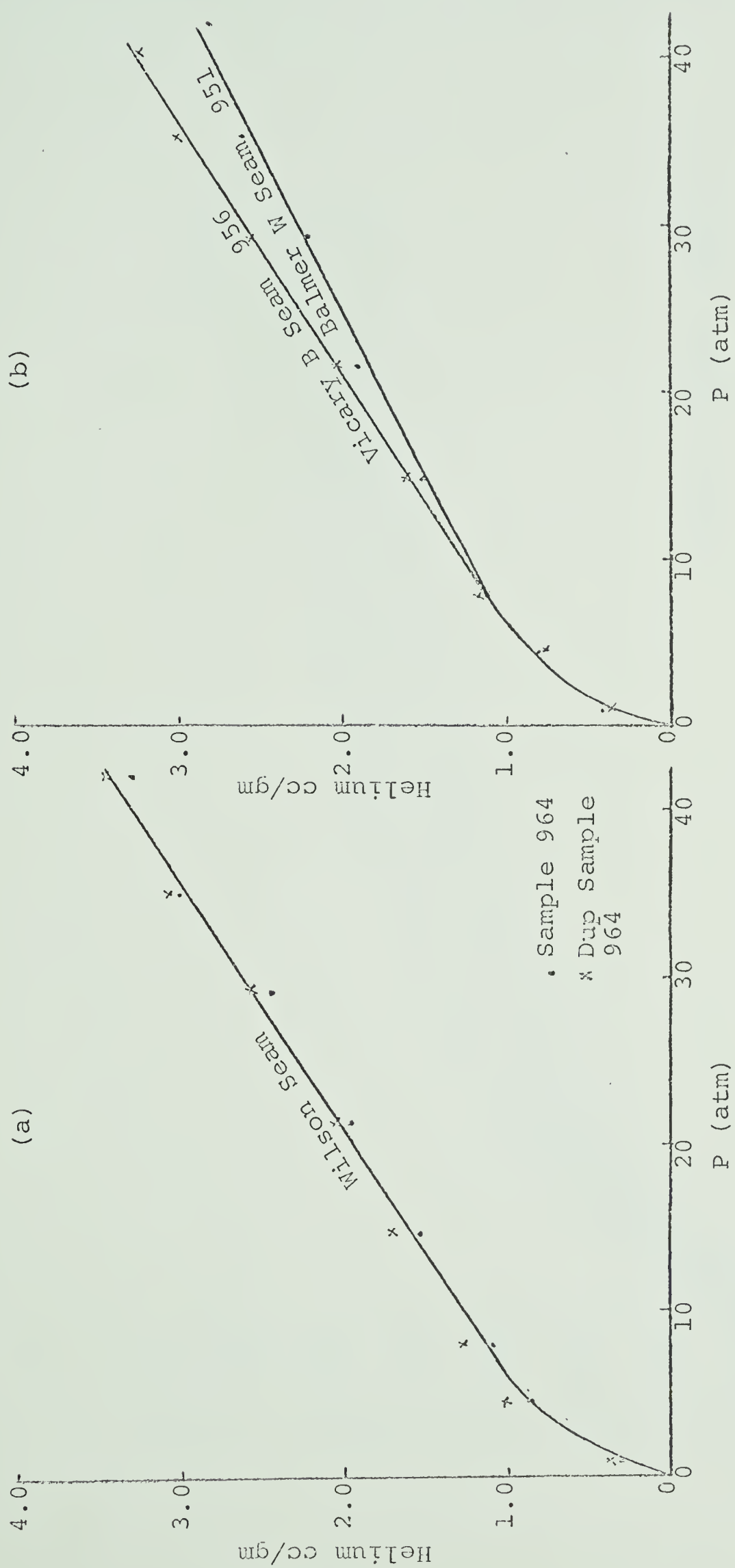


Figure 5-9. Plots of Helium Against Pressure Atm.

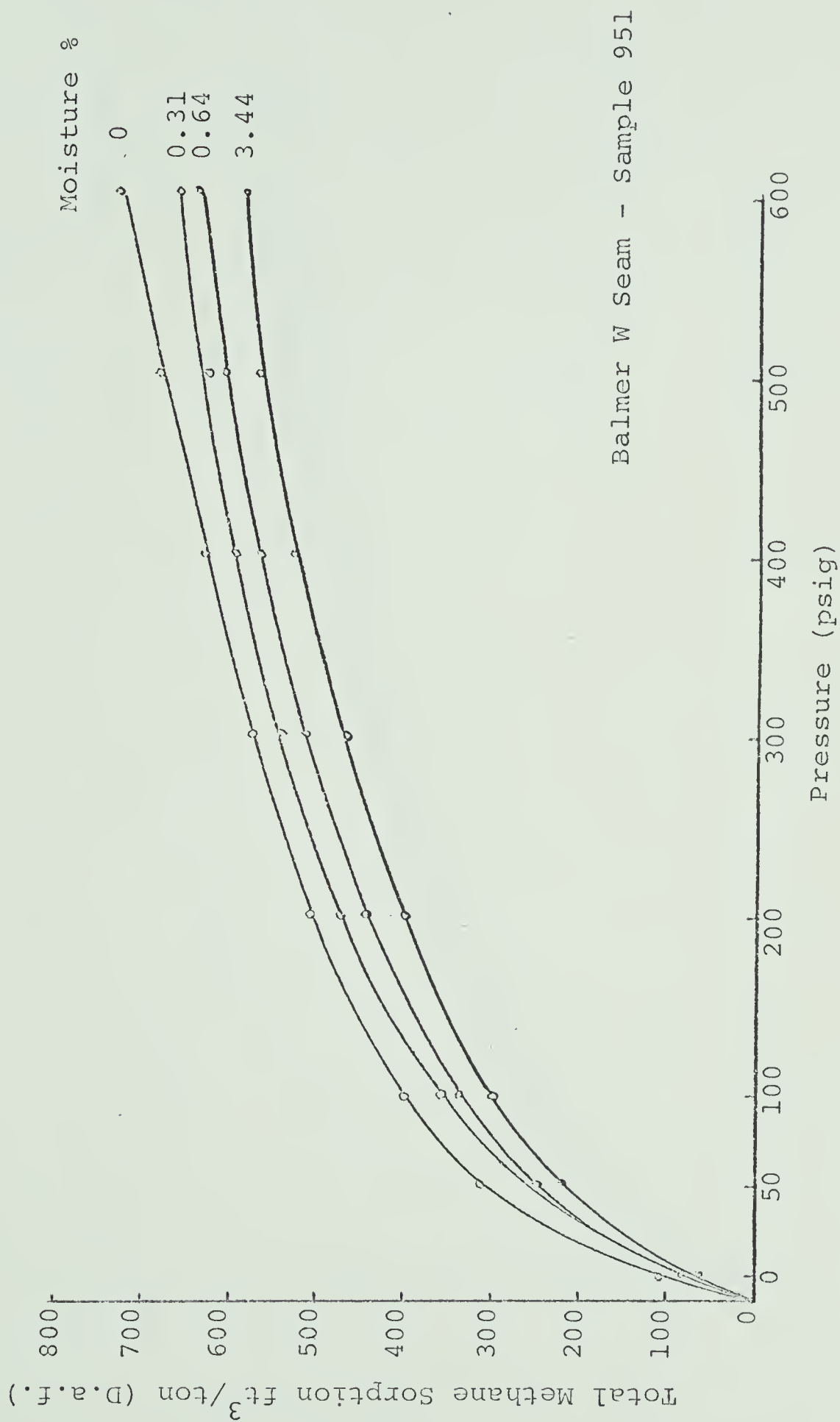


Figure 5-10. Effect of Moisture on Sorption

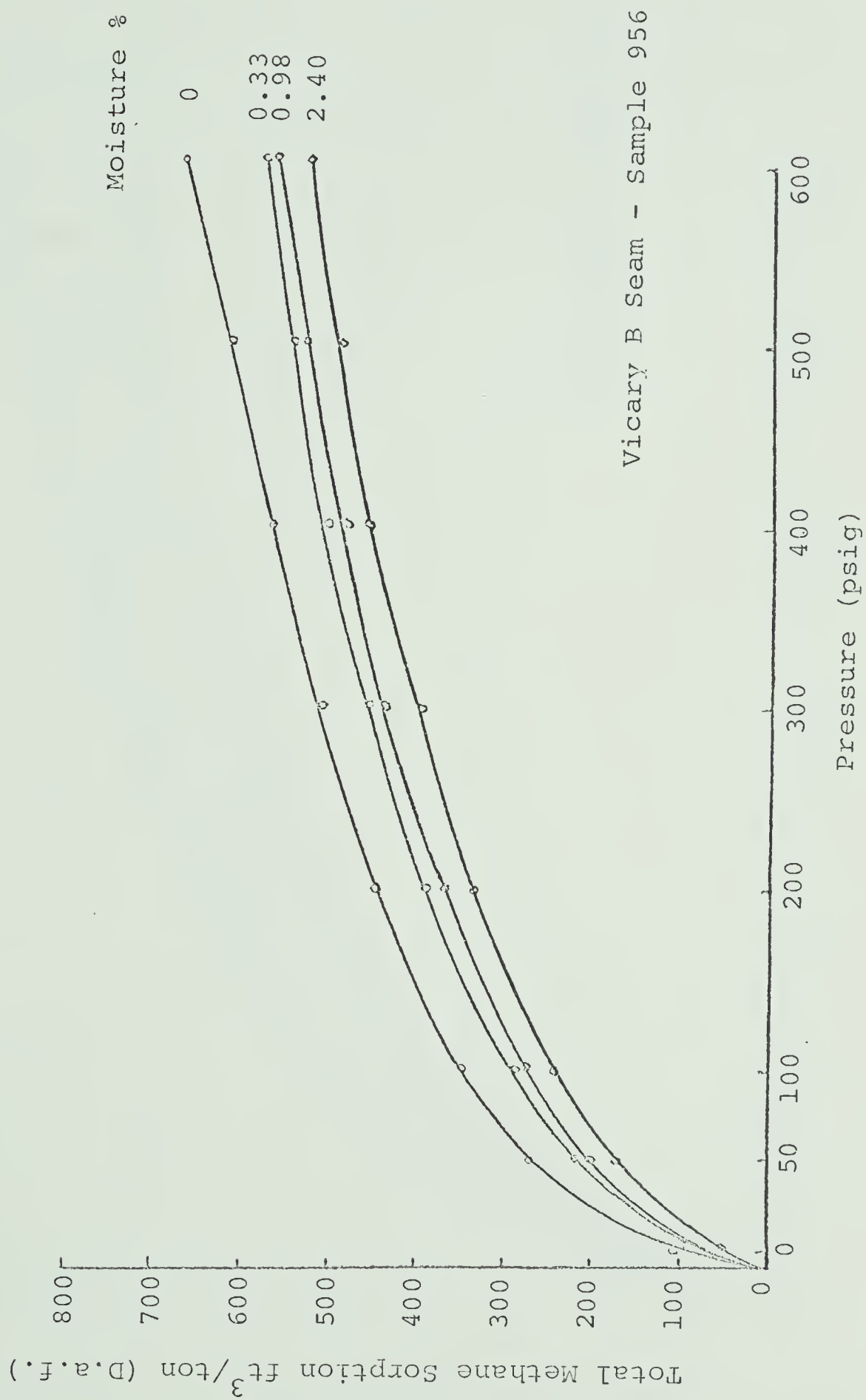


Figure 5-11. Effect of Moisture on Sorption

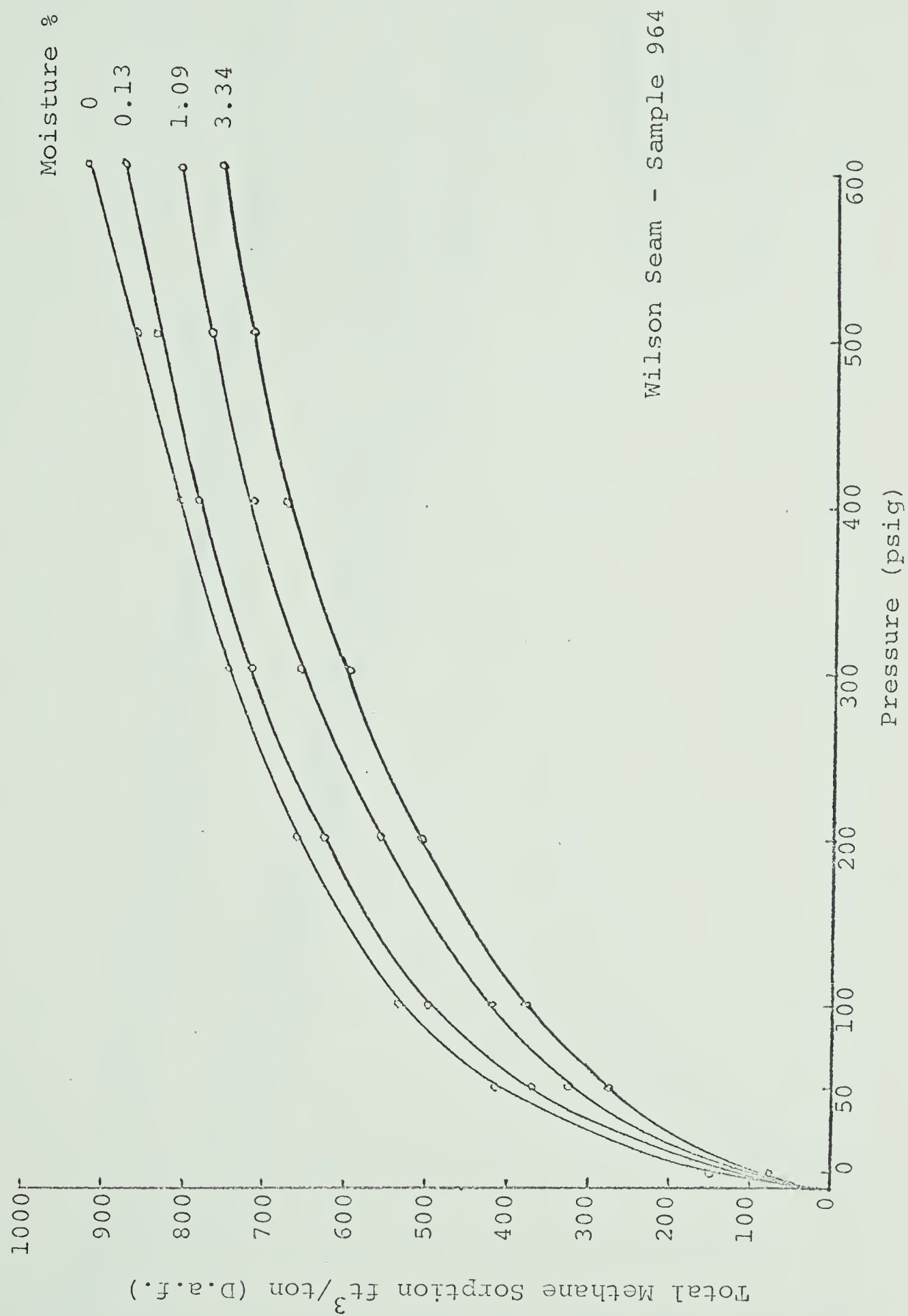


Figure 5-12. Effect of Moisture on Sorption

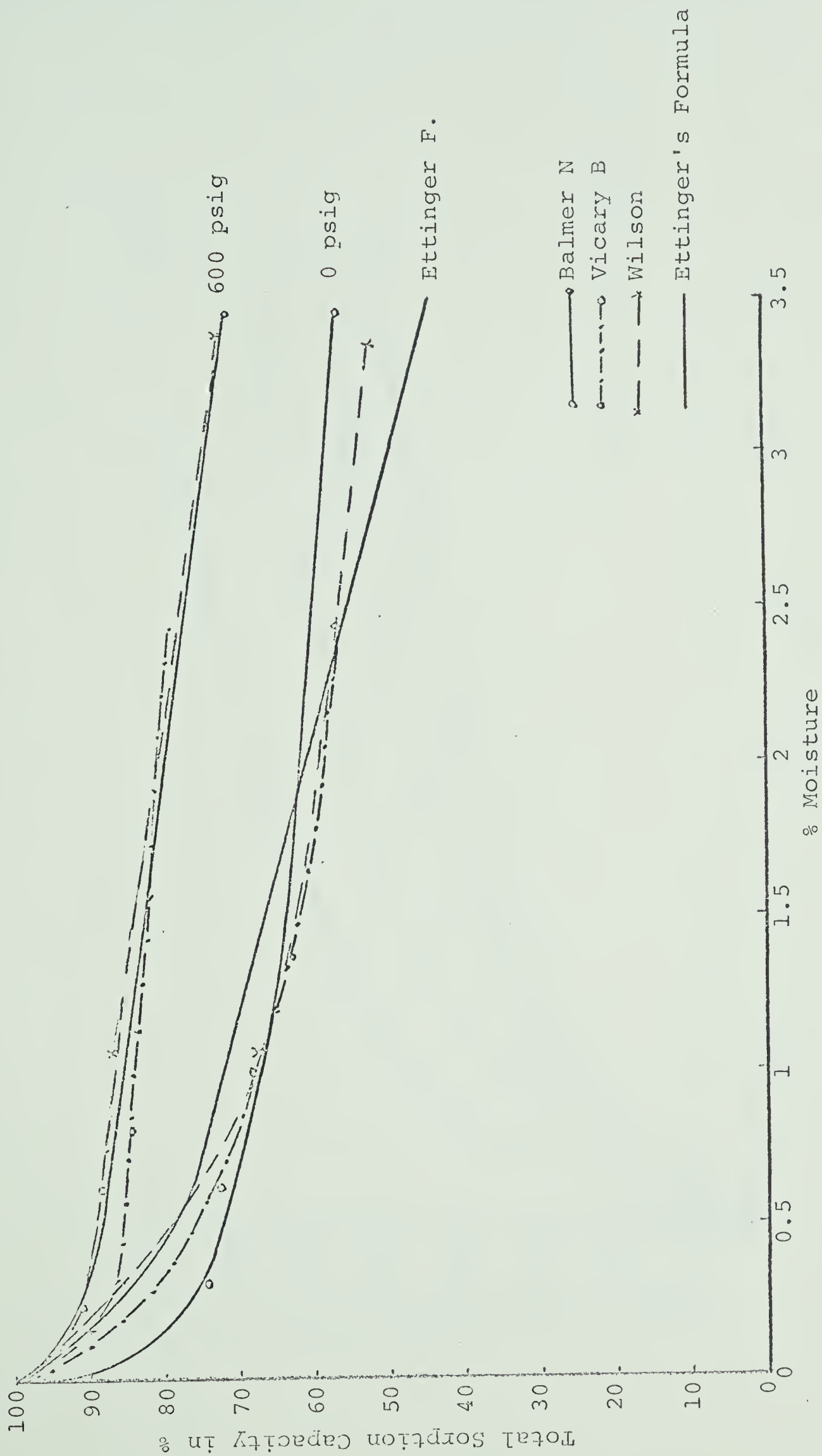
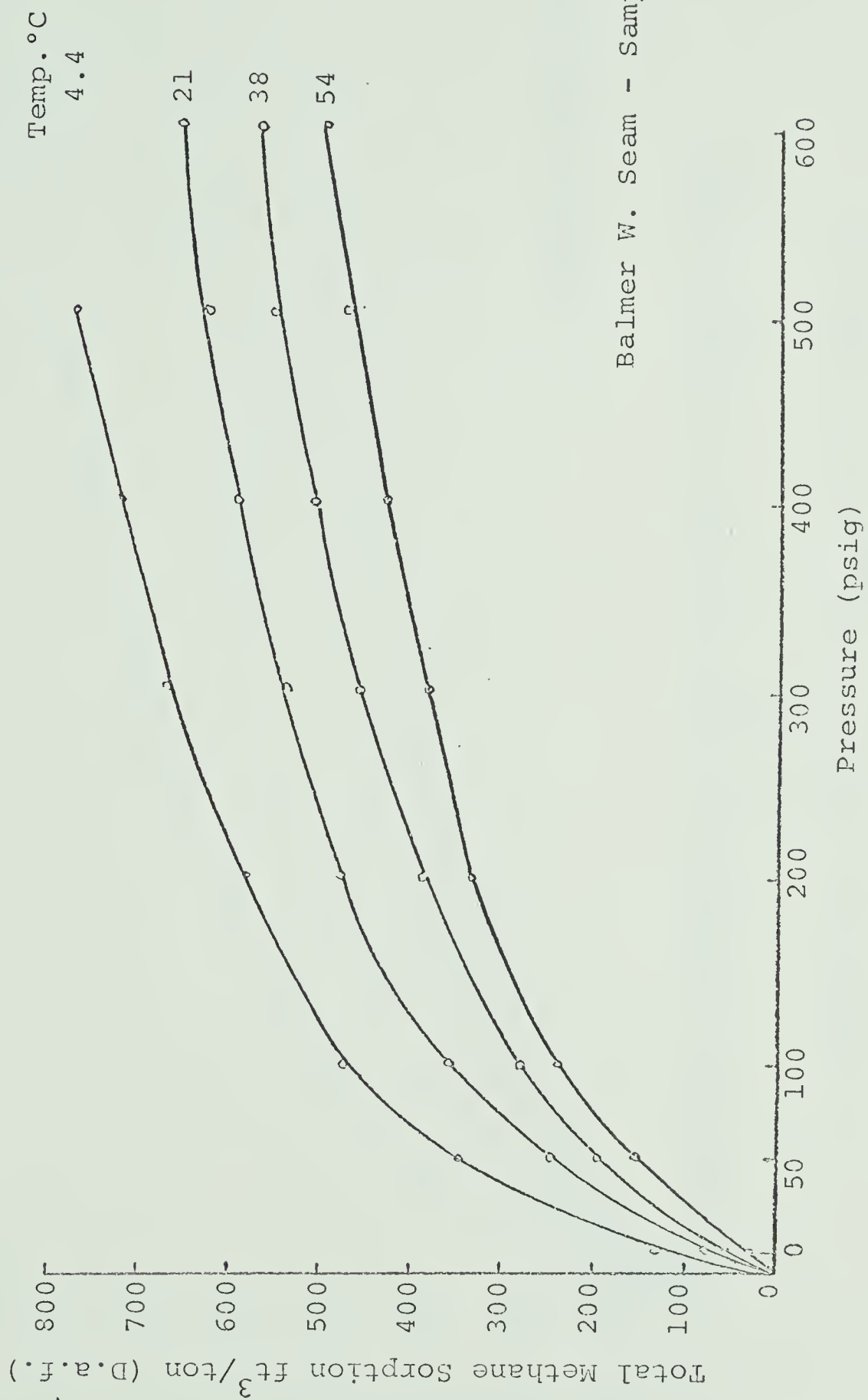


Figure 5-13. Effect of Moisture on Sorption in Percentage



Balmer W. Seam - Sample 951

Figure 5-14. Effect of Temperature on Sorption

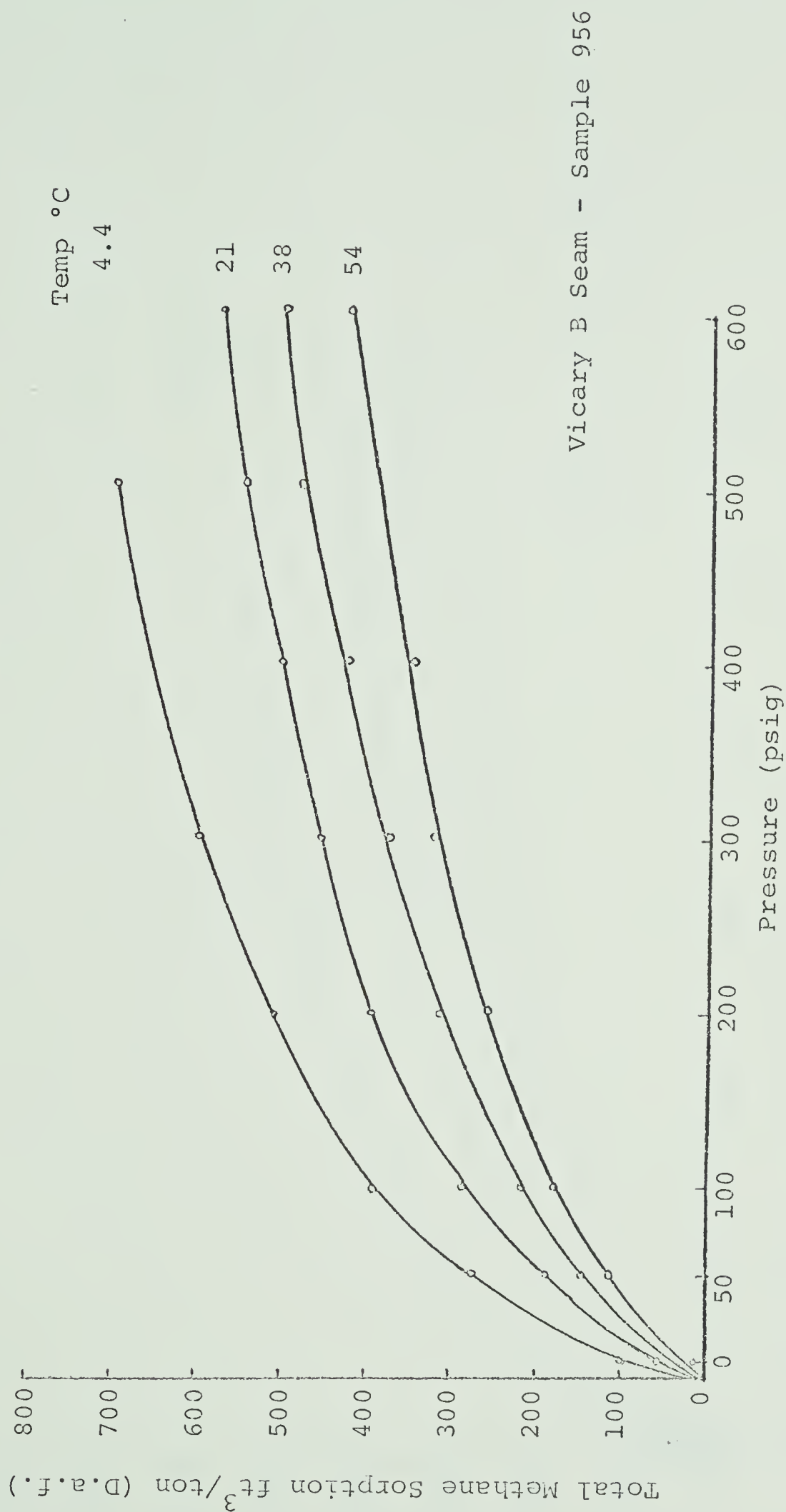


Figure 5-15. Effect of Temperature on Sorption

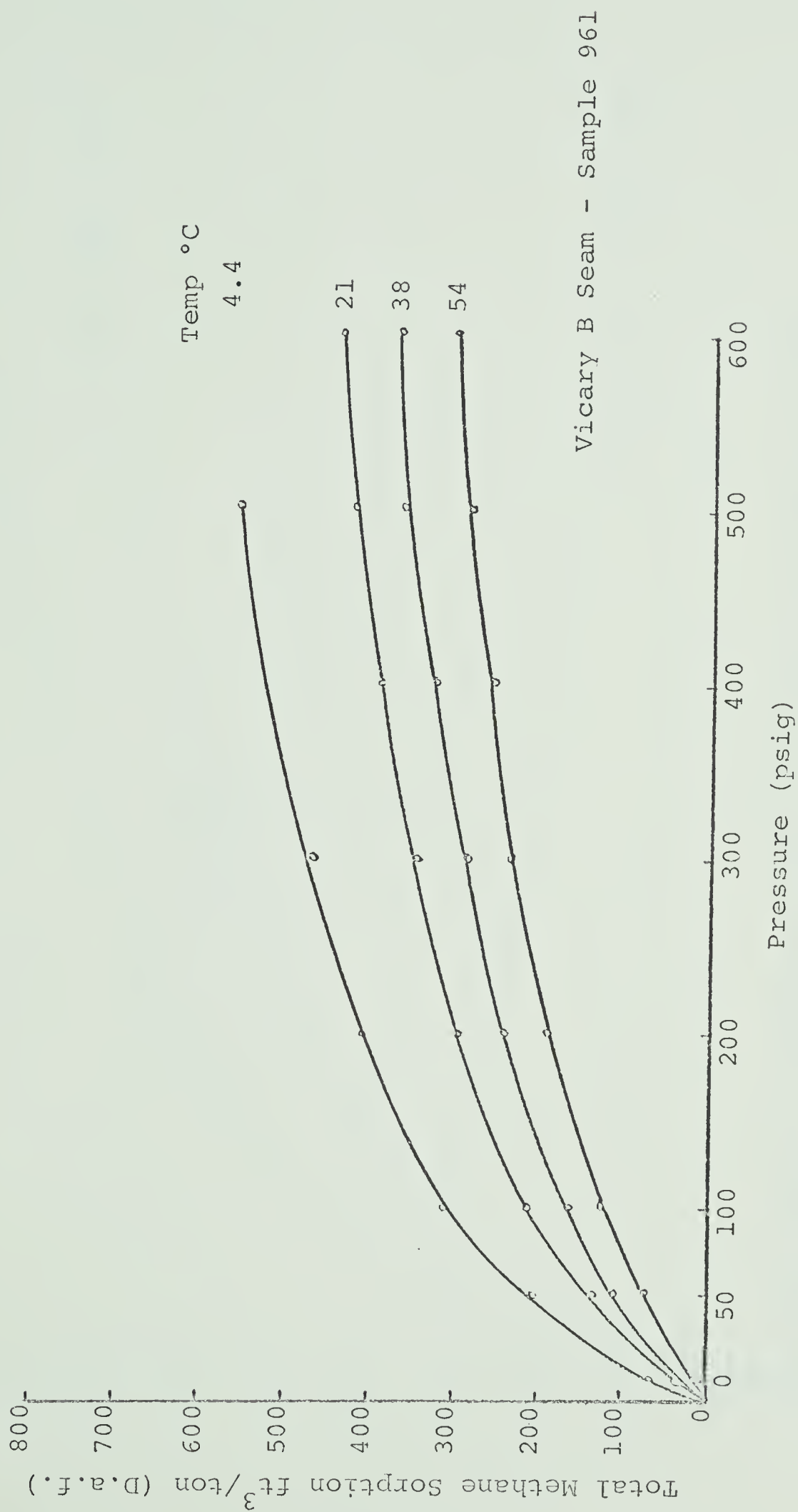


Figure 5-16. Effect of Temperature on Sorption

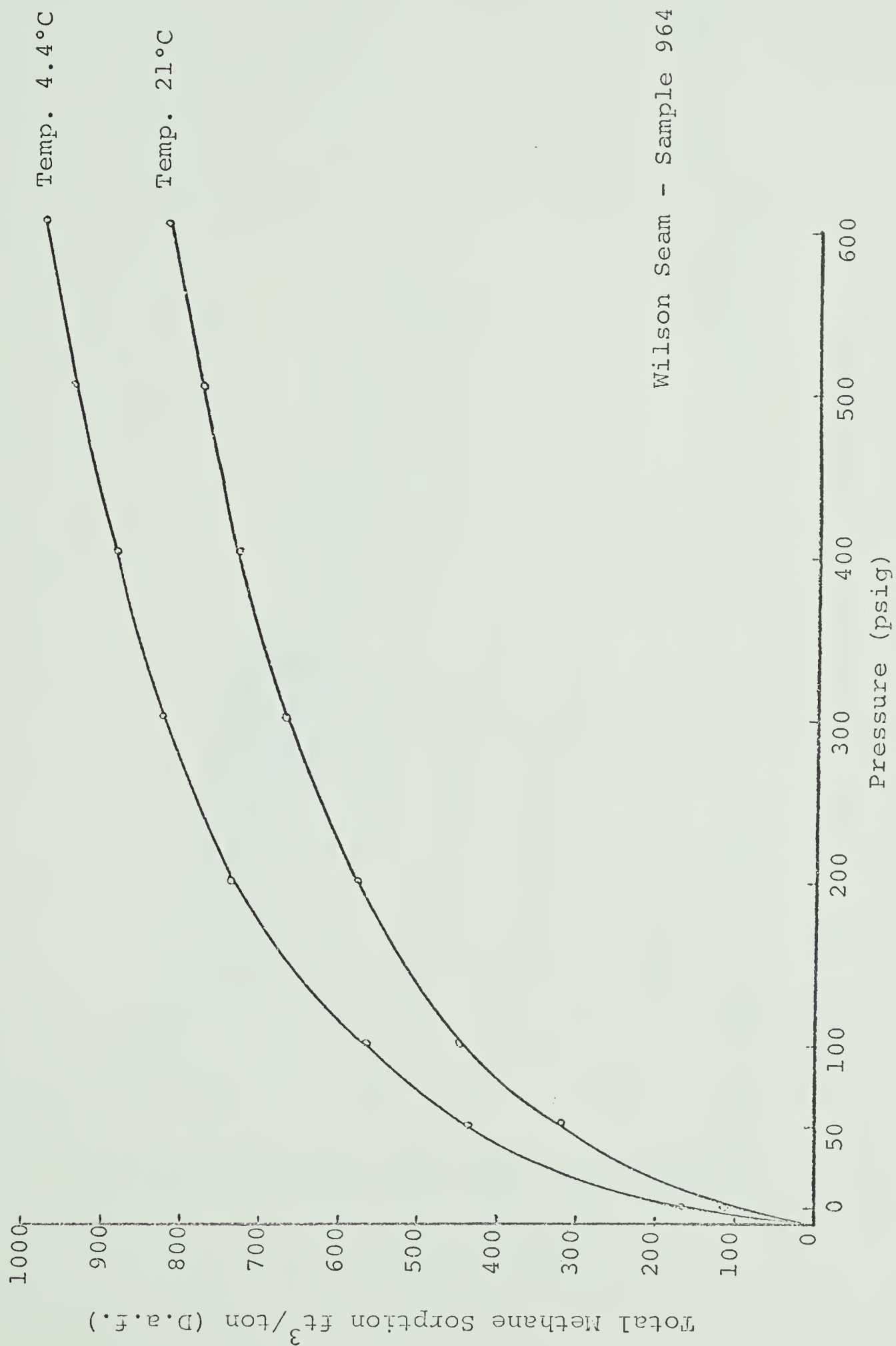


Figure 5-17. Effect of Temperature on Sorption

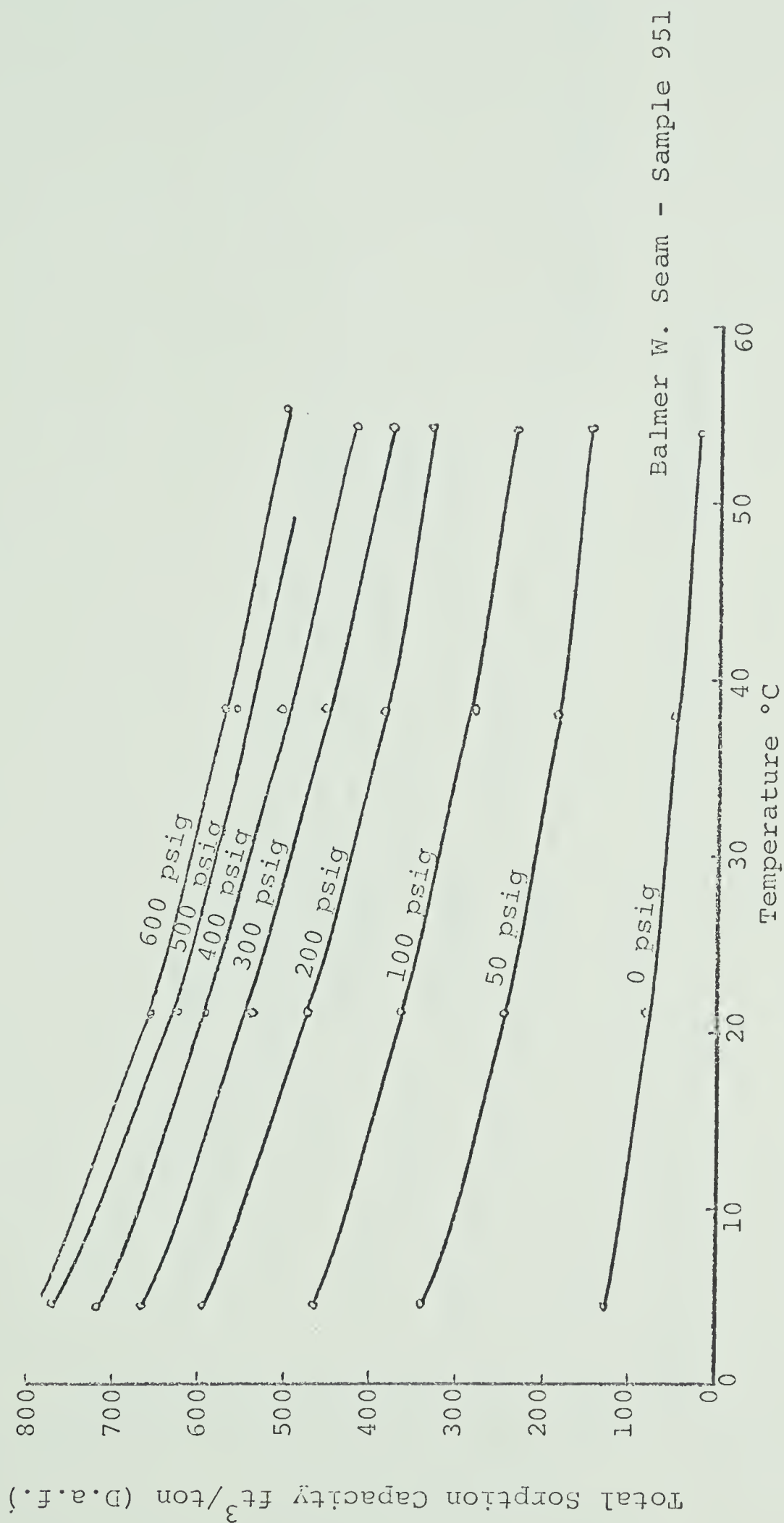
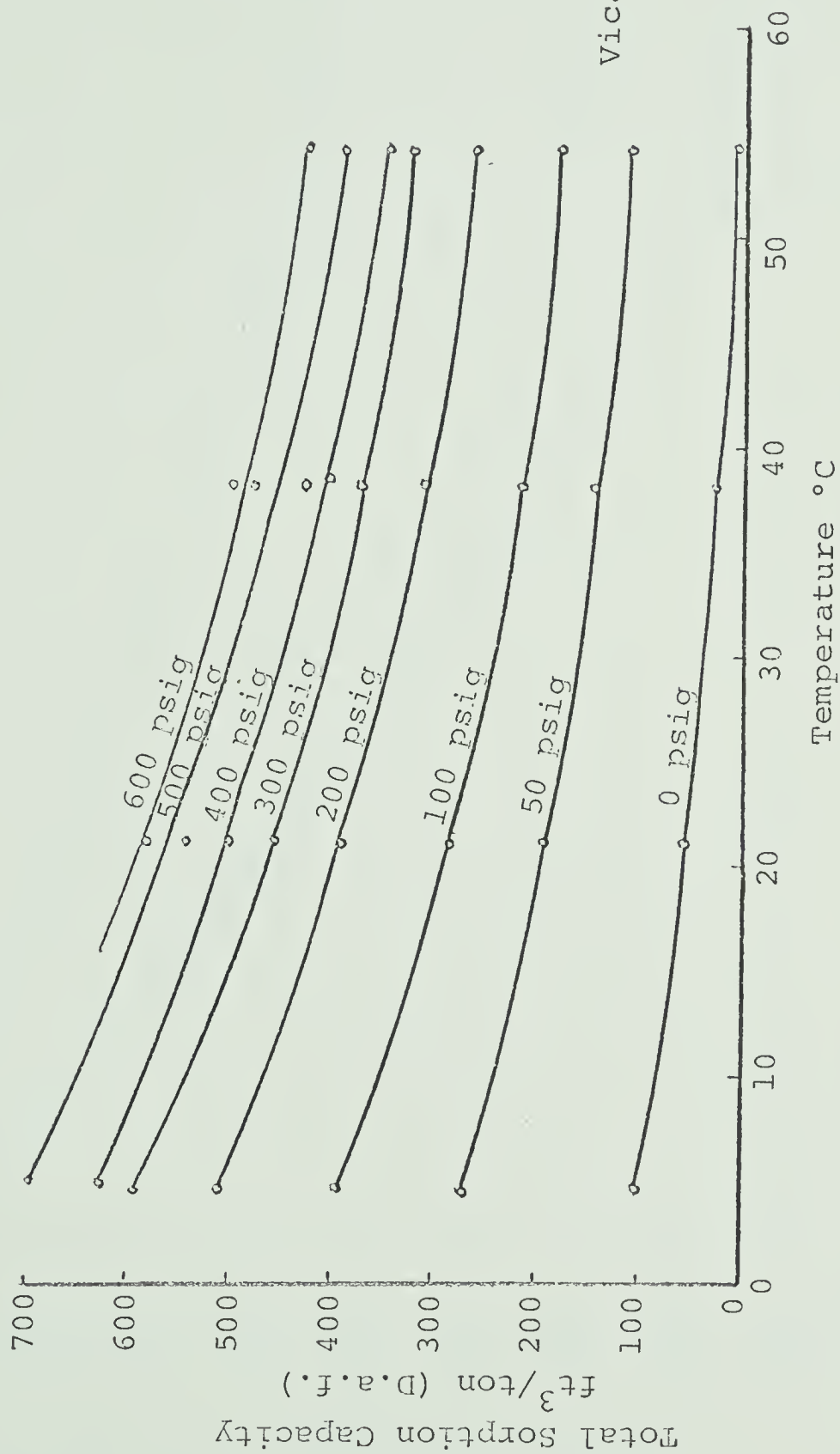


Figure 5-18. Total Sorption Against Temperature



Vicary B - Sample 956

Figure 5-19. Plot of Total Sorption Against Temperature

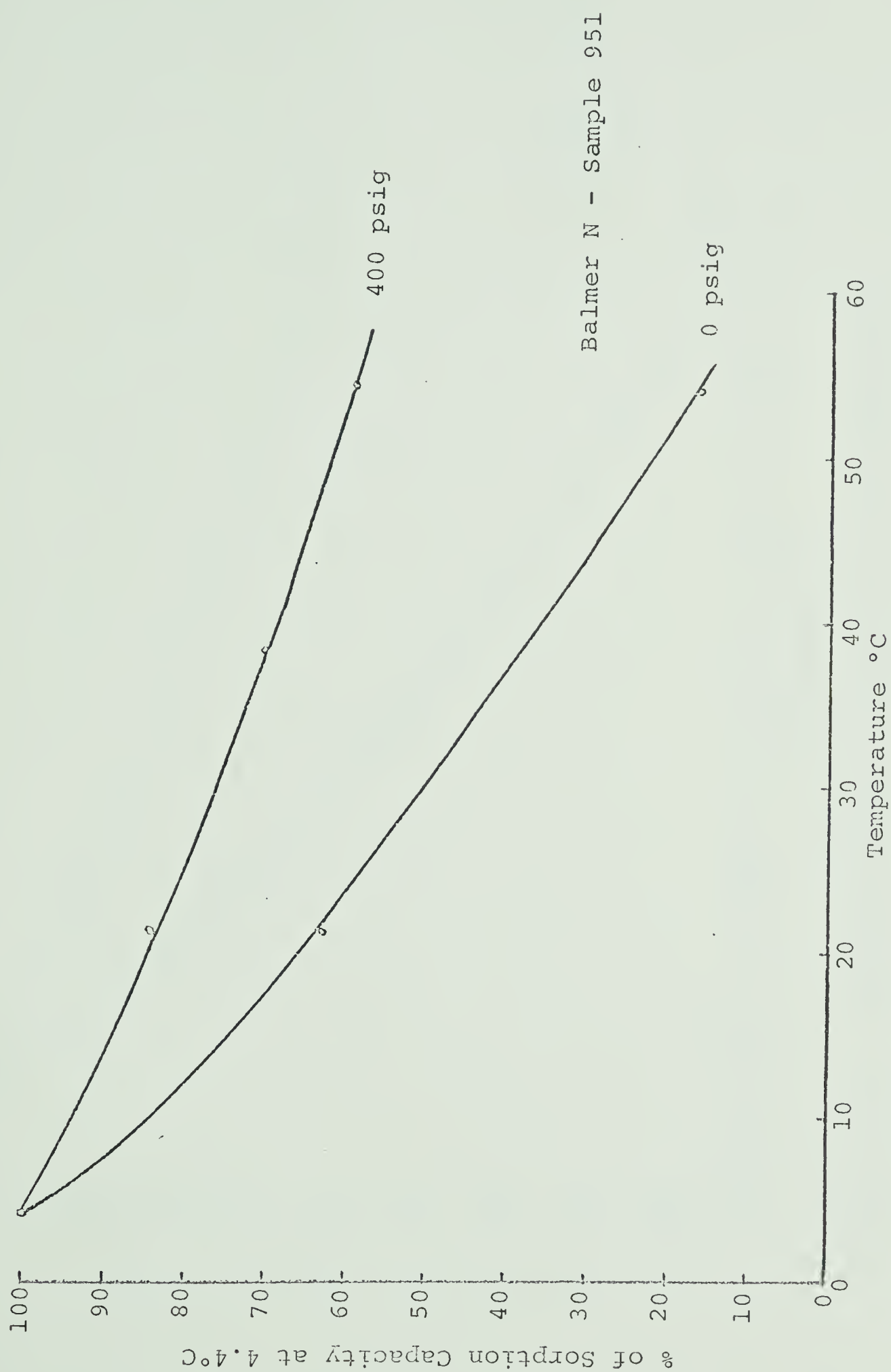


Figure 5-20. Percentage Change in Sorption with Temperature

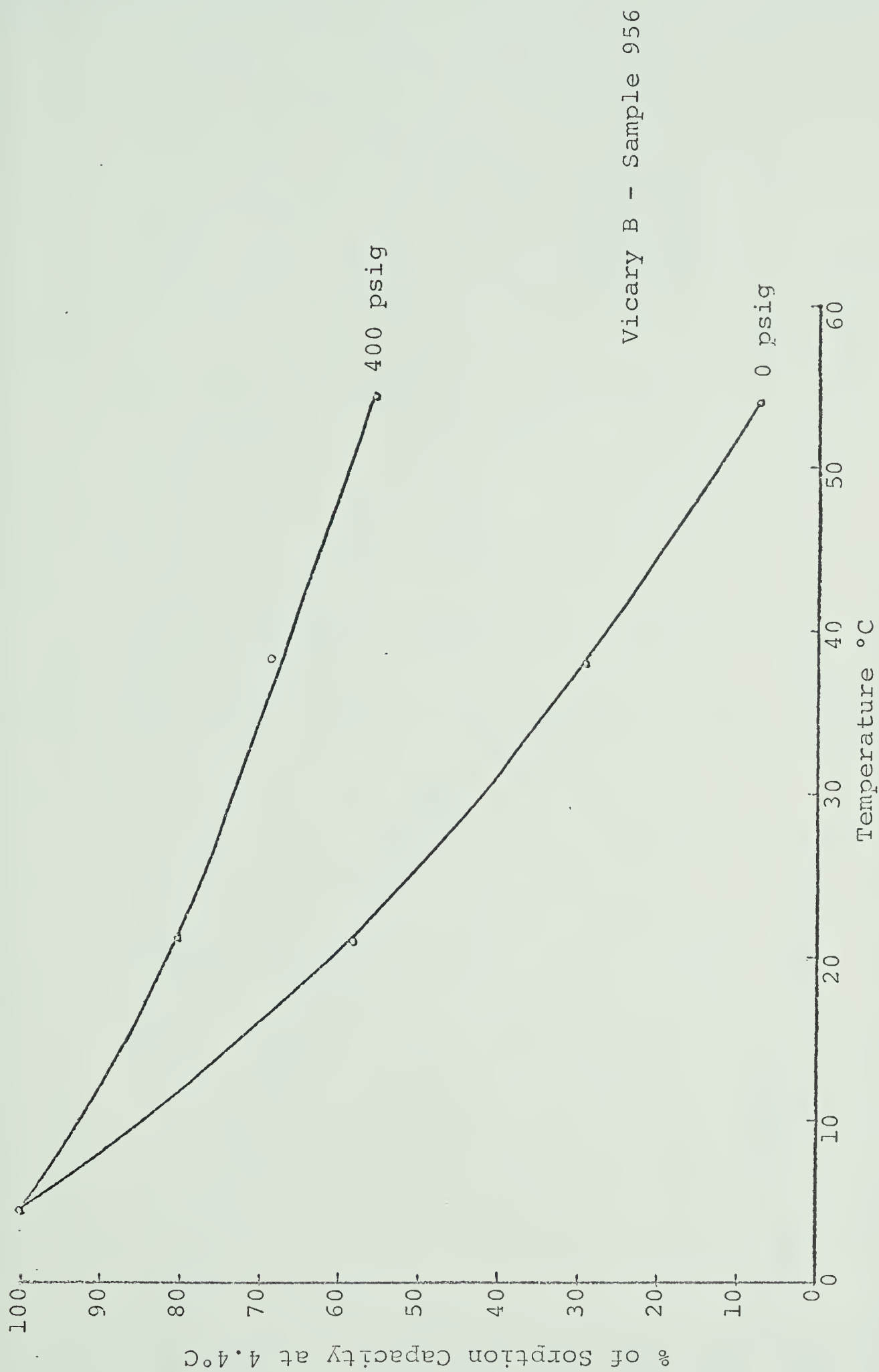


Figure 5-21. Percentage Change in Sorption with Temperature



Figure 5-22. Plot of Total Sorption Against Fixed Carbon

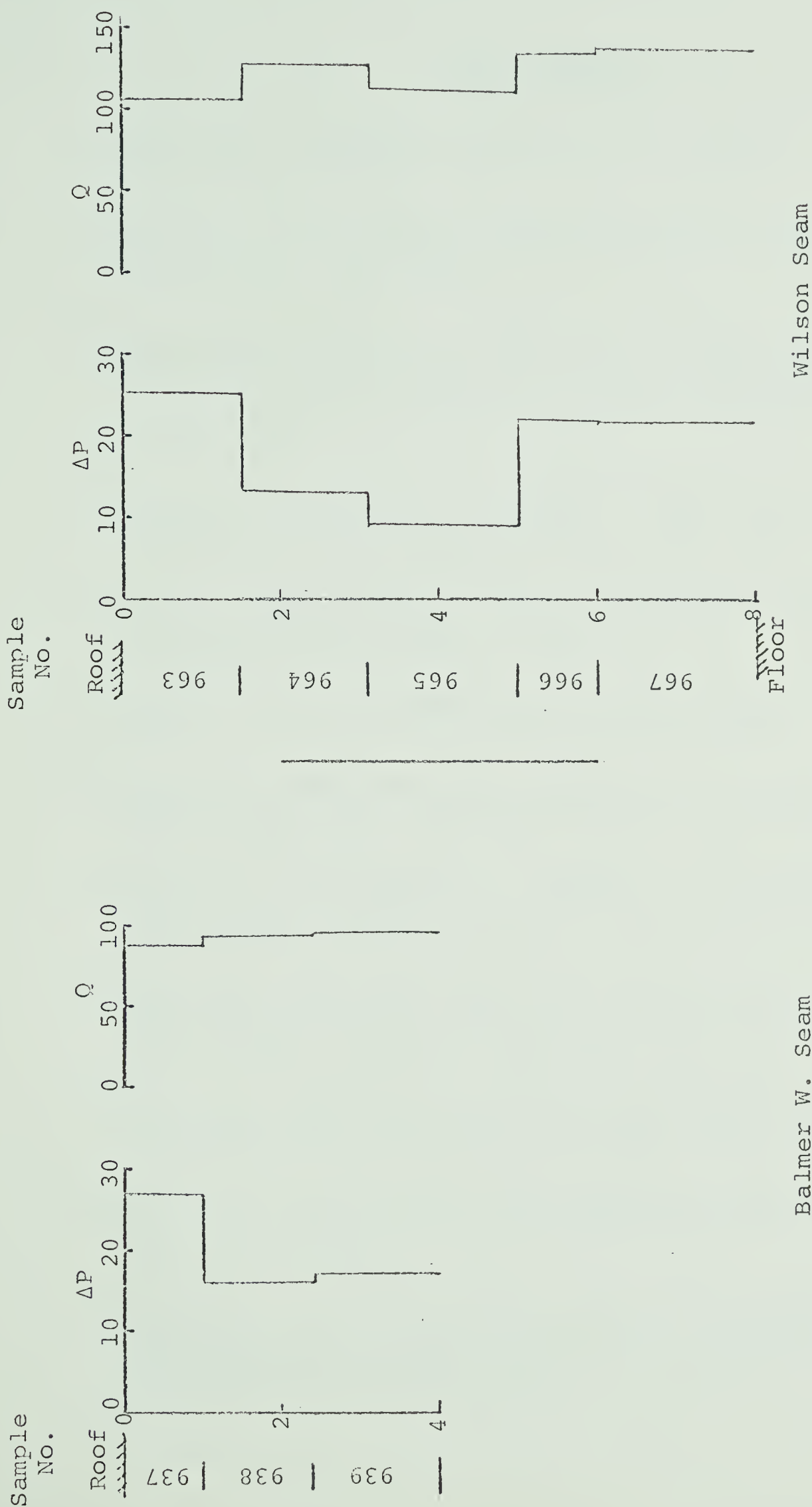


Figure 5-23. Diagram of Total Sorption at 0 psig and ΔP Index Across the Width of Two Seams.

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APPENDIX

University of Alberta
Department of Mining and Metallurgy

Gas Sorption of Coal by Weighing Method

Coal Sample #	951	Cell No.	1	Test	2
Source	Balmer N, Balmer West Seam	Std. Vol.	30.0 ml	Date	May 19, 1970
App. Sp. Gr.	1.337	Wt. of Coal & Bottom	Approx. 98.5021	Room Temp.	22 C°
Treatment	Charging CH ₄ at different pressures 0 - 600 psi	Wt. of Bottom	Precise 58.3921 "	Gas	CH ₄
Rel. Hum.	0.31 %	Net Wt. of Coal	40.1100 "	St. Cell Wt.	177.4706
		Total Wt. after Evac.	179.6563 "	Bar.	707 mmHg.

Step No.	Changing Time Clock	Net	Bar mm Hg.	Cab. Temp C°	P psi	Total Wt gms	Wt. of Gas	Wt. of Calib. Cell	Corr. For B. Change	Net Wt. of T. Gas	Wt. Cell + SV + Gas	Wt. Cell + SV	Wt. Free Gas	Wt. Sorbed Gas	Total Sorption Capacity cm ³ /gm	ft ³ /ton
1	-	2	707	21.1	0	179.7324	0.0761	177.4705	+1	0.0762	181.6098	181.5984	0.0114	0.0648	2.25	72.24
1	-	2	707	"	50	179.9135	0.2572	177.4693	+13	0.2585	181.6564	181.5984	0.0580	0.2005	6.98	223.51
1	-	2	707	"	100	180.0597	0.4034	177.4706	0	0.4034	181.7101	181.5984	0.1117	0.2917	10.15	325.17
1	-	2	707	"	200	180.2663	0.6100	177.4714	-8	0.6092	181.8196	181.5984	0.2212	0.3880	13.50	432.52
1	-	2	707	"	300	180.4315	0.7752	177.4715	-9	0.7743	181.9332	181.5984	0.3348	0.4395	15.29	489.93
1	-	2	708	"	400	180.5967	0.9404	177.4740	-34	0.9370	182.0513	181.5984	0.4529	0.4841	16.84	539.65
1	-	2	706	"	500	180.7393	1.0830	177.4733	-27	1.0803	182.1712	181.5984	0.5728	0.5075	17.66	565.74
1	-	2	706	"	600	180.8876	1.2313	177.4715	-9	1.2304	182.2928	181.5984	0.6944	0.5360	18.65	597.51

APPENDIX (cont'd)

Calculation for Total Sorbed Gas by the Gravimetric Method

From the Gas Law

$$VP = \frac{wRKT}{M}$$

where V = gas volume, cm^3 P = gas pressure, atmosphere w = weight of gas, grams R = gas constant = $82.05 \text{ cc-atm degree}^{-1} \text{ mole}^{-1}$ K = compressibility factor of gas T = absolute temperature M = molecular weight of gas (=16.04 for methane, 44.1 for carbon dioxide and 4.00 for helium)

Volume of retained gas at one atmosphere pressure/gm of

$$\text{coal} = \frac{wRKT}{MW} \text{ cm}^3/\text{gm}$$

where W = weight of coal sample in grams

$$\text{Volume of retained gas in cu.ft./ton} = \frac{wRKT}{MW} \times C$$

where c is the conversion factor from cc/gm to cu.ft./ton

$$= \frac{10^6 \times 1}{28.31 \times 1.102} = 32.04$$

Example:

A portion of 40.110 of coal retained 0.6284 gms of methane. To express this as cu.ft./ton at NTP

$$P = 1 \text{ atm} \quad T = 273 \quad K = 1 \quad M = 16.04$$

$$\therefore \text{Total sorbed methane} = \frac{0.6284 \times 82.05 \times 1 \times 273}{16.04 \times 40.11} \times 32.04$$

$$= 700.5 \text{ cu.ft./ton}$$

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